FRONTISPIECE. A Brazilian Forest Interior with Air Plants and Lianas.

ELEMENTS OF BOTANY

BY

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REVISED EDITION

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PREFACE

This revised edition of the author's *Elements of Botany*, first published in 1896, is intended to retain all that was found most useful in the original book and to deal with a few topics somewhat more fully than was done in the first edition.

The account of various types of germination and the discussion of the histology of the root, the stem, and the leaf of phanerogams have been somewhat curtailed. Experience has shown that those subjects were treated rather more fully than is necessary for a botany course of a half year or less. The time saved by the briefer treatment of the above-mentioned topics (and a few others) in the present book may profitably be devoted to a somewhat more careful study of typical cryptogamic forms and an outline of the ecological classification of plants. Accordingly directions for the study of Bacteria, *Puccinia*, *Agaricus*, and *Equisetum* have been added and the forms discussed in the older book receive more attention. A brief chapter (Chapter XII) on the ecology of leaves, with a statement of the ecological classes of plants in their relations to the needed supply of water, has been inserted. A statement of the general characteristics of cryptogams and a few notes on the evolutionary history of plants constitute the closing chapter.

Within less than a decade the standard of excellence in mechanical execution for botany text-books of every grade has been greatly raised. No pains have been spared to make this revision wholly satisfactory as regards typography and

illustrations. It will be noticed that the attractive but often *indefinite halftone style of illustration has been sparingly* employed and for the sake of giving broad effects only, not for details.

The acknowledgments made in the respective prefaces to the original edition of the *Elements of Botany* and to the *Foundations of Botany*, concerning sources from which illustrations have been derived, need not here be repeated. Neither is it necessary to recapitulate the names of those whose aid and counsel gave to the books above mentioned much of whatever value they may have been found to possess.

Several pen drawings from nature have been made by Mr. E. N. Fischer of Boston, and figures 2, 46, 52, and 53 have been redrawn by him from Percival's *Agricultural Botany*. Plates I, VII, IX, and X are from original drawings by Mr. Fischer, and numbers XIV, XV, and XVI have been copied by him from Kerner's *Natural History of Plants*, from a photograph furnished by the Missouri Botanical Garden, and from Schimper's *Pflanzengeographie*, respectively.

Plate XIII is from a drawing by Mr. Charles Copeland of Boston.

Plates XI and XII are from photographs by Mr. E. H. Baynes of Stoneham, Mass.

The remaining plates are from photographs selected by the author or taken under his direction.

J. Y. B.

NAPLES, ITALY,
June, 1904.

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INTRODUCTION

The Plant is a living being, provided generally with many parts, called *organs*, which it uses for taking in nourishment, for breathing, for protection against its enemies, and for reproducing itself and so keeping up the numbers of its own kind. The study of the individual plant therefore embraces a variety of topics, and the examination of its relation to others introduces many more subjects.

Morphology, or the science of form, structure, and so on, deals with the plant without much regard to its character as a living thing. Under this head are studied the forms of plants and the various shapes or disguises which the same sort of organ may take in different kinds of plants, their gross structure, their microscopical structure, their classification, and the successive stages in the development of the individual plant.

Plant Physiology treats of the plant in action, how it lives, breathes, feeds, grows, and produces others like itself.

Geographical Distribution, or botanical geography, discusses the range of the various kinds of plants over the earth's surface. Another subdivision of botany, usually studied along with geology, describes the history of plant

life on the earth from the appearance of the first plants until the present time.

Systematic Botany, or the classification of plants, should naturally follow the examination of the groups of seed-plants and spore-plants.

Plant Ecology treats of the relations of the plant to the conditions under which it lives. Under this division of the science are studied the effects of soil, climate, and friendly or hostile animals and plants on the external form, the internal structure, and the habits of plants. This is in many respects the most interesting department of botany, but it has to be studied for the most part out of doors.

Economic Botany is the study of the uses of plants to man.

Many of the topics suggested in the above outline cannot well be studied in the high school. It ought, however, to be possible for the student to learn in his high-school course a good deal about the simpler facts of morphology and of vegetable physiology. It is necessary to study plants themselves, to take them to pieces and to make out the connection of their parts, to examine with the microscope small portions of the exterior surface and thin slices of all the variously built materials or *tissues* of which the plant consists. Living plants must be studied in order to ascertain what kinds of food they take, what kinds of waste substances they excrete, how and where their growth takes place and what circumstances favor it, how they move, and indeed to get as complete an idea as possible of what has been called the behavior of plants.

Since the most familiar and most interesting plants spring from seeds, the beginner in botany can hardly do

better than to examine at the outset the structure of a few familiar seeds, then sprout them and watch the growth of the seedlings which spring from them. Afterwards he may study in a few typical examples the organs, structure, and functions of seed-plants, trace their life history, and so, step by step, follow the process by which a new crop of seeds at last results from the growth and development of such a seed as that with which he began.

After he has come to know in a general way about the structure and functions of seed-plants, the student may become acquainted with some typical cryptogams or spore-plants. There are so many groups of these that only a few representative ones can be chosen for study.

CHAPTER I

THE SEED AND ITS GERMINATION

1. Germination of the Squash Seed. — Soak some squash seeds in tepid water for twelve hours or more. Plant these about an inch deep in damp sand or pine sawdust or peat-moss in a wooden box which has had enough holes bored through the bottom so that it will not hold water. Put the box in a warm place (not at any time over 70° or 80° Fahrenheit),[1] and cover it loosely with a board or a pane of glass. Keep the sand or sawdust moist, but not wet, and the seeds will germinate. As soon as any of the seeds, on being dug up, are found to have burst open, sketch one in this condition,[2] noting the manner in which the outer seed-coat is split, and continue to examine the seedlings at intervals of two days, until at least eight stages in the growth of the plantlet have been noted.[3]

Observe particularly how the sand is pushed aside by the rise of the young seedlings. Suggest some reason for the manner in which the sand is penetrated by the rising stem.

2. Examination of the Squash Seed. — Make a sketch of the dry seed, natural size. Note the little scar at the pointed end of the

[1] Here and elsewhere throughout the book temperatures are expressed in Fahrenheit degrees, since with us, unfortunately, the Centigrade scale is not the familiar one outside of physical and chemical laboratories.

[2] The student need not feel that he is expected to make finished drawings to record what he sees, but some kind of careful sketch, if only the merest outline, is indispensable. Practice and study of the illustrations hereafter given will soon impart some facility even to those who have had little or no instruction in drawing. Consult here Figs. 2, 6, and 9.

[3] The class is not to wait for the completion of this work (which may, if desirable, be done by each pupil at home), but is to proceed at once with the examination of the squash seed, as directed in the following sections, and to set some corn to sprouting, so that it may be studied at the same time with the germinating squashes.

seed where the latter was attached to its place of growth in the squash. Label this *hilum*. Note the little hole in the hilum; it is the *micropyle*, seen most plainly in a soaked seed. (If there are two depressions on the hilum, the deeper one is the micropyle.)

Describe the color and texture of the outer coating of the seed. With a scalpel or a very sharp knife cut across near the middle a seed that has been soaked in water for twenty-four hours. Squeeze one of the portions, held edgewise between the thumb and finger, in such a way as to separate slightly the halves into which the contents of the seed is naturally divided. Examine with the magnifying glass the section thus treated, make a sketch of it, and label the shell or covering of the seed and the kernel within this.

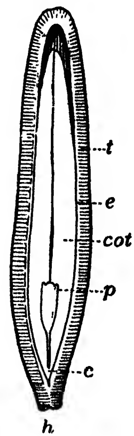


FIG. 1. Lengthwise Section of a Squash Seed. (Magnified about two and a half times.)

c, hypocotyl; *cot*, cotyledon; *e*, endosperm; *h*, hilum; *p*, plumule; *t*, testa.

Taking another soaked seed, chip away the white outer shell called the *testa*, and observe the thin, greenish inner skin (Fig. 1, *e*), with which the kernel of the seed is closely covered.[1]

Strip this off and sketch the uncovered kernel or *embryo*. Note that at one end it tapers to a point. This pointed portion, known as the *hypocotyl*, will develop after the seed sprouts into the stem of the plantlet, like that shown at *c* in Fig. 9.

Split the halves of the kernel entirely apart from each other, noticing that they are only attached for a very little way next to the hypocotyl, and observe the thickness of the halves and the slight unevenness of the inner surfaces. These halves are called seed-leaves or *cotyledons*.

Have ready some seeds which have been soaked for twenty-four hours and then left in a loosely covered jar on damp blotting paper at a temperature of 70° or over until they have begun to sprout.

Split one of these seeds apart, separating the cotyledons, and observe, at the junction of these, two very slender pointed objects, the rudimentary leaves of the *plumule* or first bud.

[1] See footnote 2 to Sect. 18.

3. Examination of the Bean. — Study the seed, both dry and after twelve hours' soaking, in the same general way in which the squash seed has just been examined.[1]

Notice the presence of a distinct plumule, consisting of a pair of rudimentary leaves between the cotyledons, just where they are joined to the top of the hypocotyl. In many seeds (as the pea) the plumule does not show distinct leaves. But in all cases the plumule contains the *growing point*, the tip of the stem from which all the upward growth of the plant is to proceed.

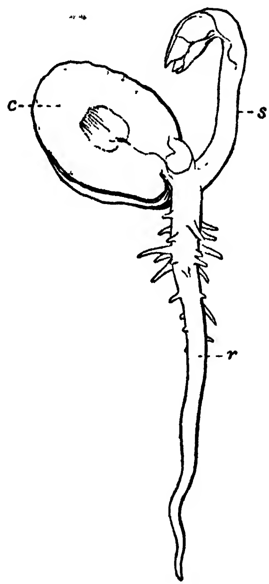


Fig. 2. Young Seedling of Windsor Bean.

c, cotyledon; *r*, root; *s*, stem.

Make a sketch of these leaves as they lie in place on one of the cotyledons after the bean has been split open.

Note the cavity in each cotyledon caused by the pressure of the plumule and of the hypocotyl.[2]

4. Germination of the Grain of Corn. — Soak some grains of corn and plant them as directed in Sect. 1.[3]

Make six or more sketches at various stages to illustrate the growth of the plumule and the formation of roots; first a main root from the base of the hypocotyl, then others more slender from the same region, and later on still others from points higher up on the stem. The student may be able to discover what becomes of the large outer

[1] The larger the variety of bean chosen, the easier it will be to see and sketch the several parts. The large red kidney bean, the horticultural bean, or the Lima bean will do well for this examination.

[2] The teacher will find excellent sketches of most of the germinating seeds described in the present chapter in Newell's *Outlines of Lessons in Botany*, Part I.

[3] The pupil may economize space by planting the new seeds in boxes from which part of the earlier planted seeds have been dug up for use in sketching, etc.

part of the embryo. This is really the single cotyledon of the corn (Fig. 6). It does not as a whole rise above ground, but most of it remains in the buried grain and acts as a digesting and absorbing organ through which the *endosperm* or food stored outside of the embryo is transferred into the growing plant as fast as it can be made liquid for that purpose.

5. Conditions Requisite for Germination. — When we try to enumerate the external conditions which may affect germination, we find that the principal ones are heat, moisture, and presence of air. A few simple experiments will show what influence some of these conditions exert.

6. Temperature. — Common observation shows that a moderate amount of warmth is necessary for the sprouting of seeds. Every farmer or gardener knows that during a cold spring many seeds, if planted, will rot in the ground. But a somewhat exact experiment is necessary to show what is the best temperature for seeds to grow in, and whether variations in the temperature make more difference in the quickness with which they begin to germinate or in the total per cent which finally succeed.

EXPERIMENT I

Relation of Temperature to Germination. — Prepare at least four teacups or tumblers, each with wet soft paper packed in the bottom to a depth of nearly an inch. Have a tightly fitting cover over each. Put in each vessel the same number of soaked peas. Stand the vessels with their contents in places where they will be exposed to different, but fairly constant, temperatures, and observe the several temperatures carefully with a thermometer. Take pains to keep the tumblers in the warm places from drying out, so that their contents will not be less moist than that of the others. The following

series is merely suggested,—other values may be found more convenient. Note the rate of germination in each place and record in tabular form as follows.

No. of seeds sprouted in	24 hrs.	48 hrs.	72 hrs.	96 hrs.	etc.
At 32°,	——	——	——	——	——
At 50°,	——	——	——	——	——
At 70°,	——	——	——	——	——
At 90°,[1]	——	——	——	——	——

7. Moisture.—What was said in the preceding section in regard to temperature applies also to the question of the best conditions for germination as regards the supply

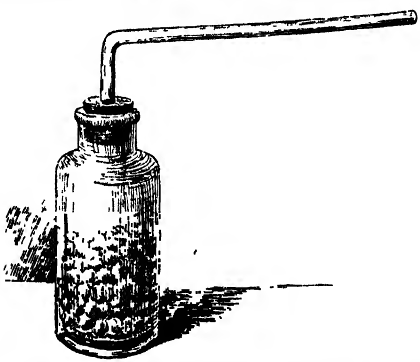


FIG. 3. Soaked Peas in Stoppered Bottle, ready for Exhaustion of Air.

of moisture. The soil in which seeds grow out of doors is always moist; most kinds germinate best in earth not nearly saturated with moisture.

8. Relation of the Air Supply to Germination.— If we wish to see how soaked seeds will behave with hardly any air supply, it is necessary to place them in a bottle arranged

[1] For the exact regulation of the temperatures a thermostat (see *Handbook*) is desirable. If one is available, a maximum temperature of 100° or over should be tried.

as shown in Fig. 3, exhaust the air by connecting the glass tube with an air-pump, which is then pumped vigorously, and seal the tube while the exhaustion is going on. The sealing is best done by holding a Bunsen flame under the middle of the horizontal part of the tube. A much easier experiment, which is nearly as satisfactory, can, however, be performed without the air-pump.

EXPERIMENT II

Will Seeds Germinate well without a Good Supply of Air? — Place some soaked seeds on damp blotting paper in the bottom of a bottle, using seeds enough to fill it three-quarters full, and close tightly with a rubber stopper.

Place a few other seeds of the same kind in a second bottle; cover loosely.

Place the bottles side by side so that they will have the same conditions of light and heat. Watch for results and tabulate as in previous experiments.

Most seeds will not germinate under water, but those of the sunflower will do so, and therefore Exp. II may be varied in the following manner.

Remove the shells carefully from a considerable number of sunflower seeds.[1] Try to germinate one lot of these in water which has been boiled in a flask to remove the air, and then cooled in the same flask. Over the water, with the seeds in it, a layer of cotton-seed oil about a half inch deep is poured, to keep the water from contact with air. In this bottle then there will be only seeds and air-free water. Try to germinate another lot of seeds in a bottle half filled with ordinary water, also covered with cotton-seed oil. Results?

9. Germination involves Chemical Changes. — If a thermometer is inserted into a jar of sprouting seeds, for

[1] These are really fruits, but the distinction is not an important one at this time.

instance peas, in a room at the ordinary temperature, the peas will be found to be warmer than the surrounding air. This rise of temperature is at least partly due to the absorption from the air of that substance in it which supports the life of animals and maintains the burning of fires, namely, *oxygen.*

The union of oxygen with substances with which it can combine, that is with those which will burn, is called *oxidation.* This kind of chemical change is universal in plants and animals while they are in an active condition, and the energy which they manifest in their growth and movements is as directly the result of the oxidation going on inside them as the energy of a steam engine is the result of the burning of coal or other fuel under its boiler. In the sprouting seed much of the energy produced by the action of oxygen upon oxidizable portions of its contents is expended in producing growth, but some of this energy is wasted by being transformed into heat which escapes into the surrounding soil. It is this escaping heat which is detected by a thermometer thrust into a quantity of germinating seeds.

EXPERIMENT III

Effect of Germinating Seeds upon the Surrounding Air. — When Exp. II has been finished, remove a little of the air from above the peas in the first bottle. This can easily be done with a rubber bulb attached to a short glass tube. Then bubble this air through some clear, filtered limewater. Also blow the breath through some limewater by aid of a short glass tube. Explain any similarity in results obtained. (Carbon dioxide turns limewater milky.) Afterwards insert into the air above the peas in the same bottle a lighted pine splinter, and note the effect upon its flame.

10. Other Proofs of Chemical Action. — Besides the proof of chemical changes in germinating seeds just described, there are other kinds of evidence to the same effect.

Malt, which is merely sprouted barley with its germination permanently stopped at the desired point by the application of heat, tastes differently from the unsprouted grain, and can be shown by chemical tests to have suffered a variety of changes. If you can get unsprouted barley and malt, taste both and see if you can decide what substance is more abundant in the malt.

Germinating kernels of corn undergo great alterations in their structure; the starch grains are gradually eaten away until they are ragged and full of holes and finally disappear.

11. The Embryo and its Development. — The miniature plant, as it exists ready formed and alive but inactive in the seed, is called the *embryo*. In the seeds so far examined, practically the entire contents of the seed-coats consist of the embryo, but this is not the case with the great majority of seeds, as will be shown in the following chapter.

CHAPTER II

STORAGE OF FOOD IN THE SEED

12. Food in the Embryo. — Squash seeds are not much used for human food, though both these and melon seeds are occasionally eaten in parts of Europe; but beans and peas are important articles of food. Whether the material accumulated in the cotyledons is an aid to the growth of the young plant may be learned from a simple experiment.

13. Mutilated and Perfect Seedlings. — One of the best ways in which to find out the importance and the special use of any part of a plant is to remove the part in question and see how the plant behaves afterward.

EXPERIMENT IV[1]

Are the Cotyledons of a Pea of any Use to the Seedling? — Sprout several peas on blotting paper. When the plumules appear, carefully cut away the cotyledons from some of the seeds. Place on a perforated cork, as shown in Fig. 4, one or two seedlings from which the cotyledons have been cut, and as many which have not been mutilated, and allow the roots to extend into the water. Let them grow for some days, or even weeks, and note results.

14. Storage of Food outside of the Embryo. — In very many cases the cotyledons contain little food, but there is a supply of it stored in the seed beside or around them (Figs. 5 and 6).

[1] May be a home experiment.

15. Examination of the Four-o'clock Seed. — Examine the external surface of a seed[1] of the four-o'clock, and try the hardness of the outer coat by cutting it with a knife. From seeds which have been soaked in water at least twenty-four hours peel off the coatings and sketch the kernel. Make a cross-section of one of the soaked seeds which has not been stripped of its coatings, and sketch the section, as seen with the magnifying glass, to show the parts, especially the two cotyledons, lying in close contact and encircling the white, starchy-looking *endosperm*.[2]

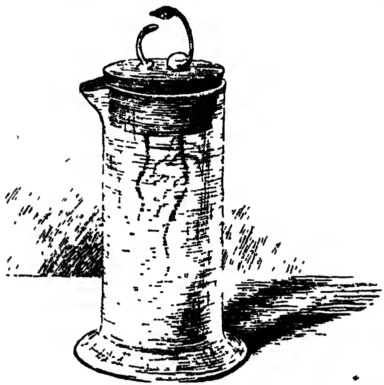
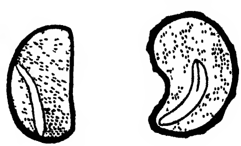


FIG. 4. Germinating Peas, growing in Water, one deprived of its Cotyledons.

The name *endosperm* is applied to food stored in parts of the seed other than the embryo.[3] With a mounted needle pick out the little almost spherical mass of endosperm from inside the cotyledons of a seed which has been deprived of its coats, and sketch the embryo, noting how it is curved so as to enclose the endosperm almost completely.



I II

FIG. 5. Seeds with Endosperm, Longitudinal Sections.

I, asparagus (magnified).
II, poppy (magnified).

16. Examination of the Kernel of Indian Corn. — Soak some grains of large yellow field corn[4] for about three days.

[1] Strictly speaking, a fruit.

[2] Buckwheat furnishes another excellent study in seeds with endosperm. Like that of the four-o'clock, it is, strictly speaking, a fruit; so also is a grain of corn.

[3] In the squash seed the green layer which covered the embryo represents the remains of the endosperm.

[4] The varieties with long, flat kernels, raised in the Middle and Southern States under the name of "dent corn," are the best.

Sketch an unsoaked kernel so as to show the grooved side where the germ lies. Observe how this groove has become partially filled up in the soaked kernels.

Remove the thin, tough skin from one of the latter and notice its transparency. This skin — the bran of unsifted corn meal — does not exactly correspond to the testa and inner coat of ordinary seeds, since the kernel of corn, like all other grains (and like the seed of the four-o'clock), represents not merely the seed, but also the seed-vessel in which it was formed and grew, and is therefore a fruit.

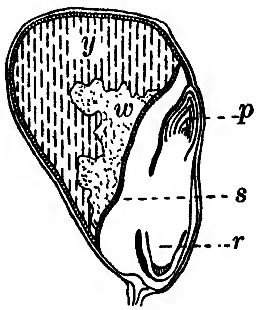


FIG. 6. Lengthwise Section of Grain of Corn. (Magnified about three times.)

y, yellow, oily part of endosperm; *w*, white, starchy part of endosperm; *p*, plumule; *s*, the shield (cotyledon), in contact with the endosperm for absorption of food from it; *r*, the primary root.

Cut sections of the soaked kernels, some transverse, some lengthwise and parallel to the flat surfaces, some lengthwise and at right angles to the flat surfaces. Try the effect of staining some of these sections with iodine solution.

Make a sketch of one section of each of the three kinds, and label the dirty white portion of cheesy consistency, *embryo;* and the yellow portions and those which are white and floury, *endosperm.*

Chip off the endosperm from one kernel so as to remove the embryo free from other parts.[1] Notice its form, somewhat triangular in outline, sometimes nearly the shape of a beechnut, in other specimens nearly like an almond.

Estimate what proportion of the entire bulk of the soaked kernel is embryo.

Split the embryo lengthwise so as to show the slender, somewhat conical plumule.[2]

[1] The embryo may be removed with great ease from kernels of rather mature green corn. Boil the corn for about twenty minutes on the cob, then pick the kernels off one by one with the point of a knife. They may be preserved indefinitely in alcohol of 50% or 75%.

[2] The teacher may well consult Figs. 56–61, inclusive, in Gray's *Structural Botany*.

17. Starch. — Most common seeds contain starch. Every one knows something about the appearance of ordinary commercial starch as used in the laundry and as sold for food in packages of cornstarch. When pure it is characterized not only by its lustre, but also by its peculiar velvety feeling when rubbed between the fingers.

18. The Starch Test. — It is not always easy to recognize at sight the presence of starch as it occurs in seeds, but it may be detected by a very simple chemical test, namely, the addition of a solution of iodine.[1]

EXPERIMENT V[2]

Examination of Familiar Seeds with Iodine. — Cut in two with a sharp knife the seeds to be experimented on, then pour on each, drop by drop, some of the iodine solution. Only a little is necessary; sometimes the first drop is enough.

If starch is present, a blue color (sometimes almost black) will appear. If no color is obtained in this way, boil the pulverized seeds for a moment in a few drops of water, and try again.

Test in this manner corn, wheat (in the shape of flour), oats (in oatmeal), barley, rice, buckwheat, flax, rye, sunflower, four-o'clock, morning-glory, mustard seed, beans, peanuts, Brazil-nuts, hazelnuts, and any other seeds that you can get. Report your results in tabular form as follows.

Much Starch	Little Starch	No Starch
Color: blackish or dark blue	Color: pale blue or greenish	Color: brown, orange, or yellowish

[1] The tincture of iodine sold at the drug-stores will do, but the solution prepared as directed in the *Handbook* answers better. This may be made up in quantity and issued to the pupils in drachm vials, to be taken home and used there if the experimenting must be done outside of the laboratory or the schoolroom.

[2] May be a home experiment.

19. Microscopical Examination of Starch.[1] — Examine starch in water with a rather high power of the microscope (not less than 200 diameters).

Pulp scraped from a potato, that from a canna rootstock, wheat flour, the finely powdered starch sold under the commercial name of "cornstarch" for cooking, oatmeal, and buckwheat finely powdered in a mortar, will furnish excellent examples of the shape and markings of starch grains. Sketch all of the kinds examined, taking pains to bring out the markings.[2] Compare the sketches with Figs. 7 and 8.

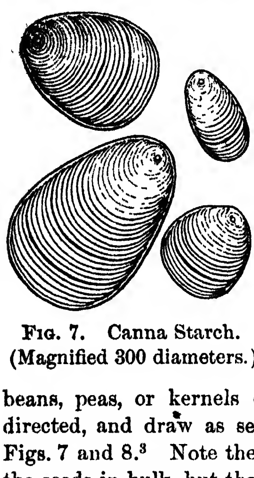


FIG. 7. Canna Starch. (Magnified 300 diameters.)

With a medicine-dropper or a very small pipette run a drop of iodine solution under one edge of the cover-glass, at the same time withdrawing a little water from the margin opposite by touching to it a bit of blotting paper. Examine again and note the blue coloration of the starch grains and the unstained or yellow appearance of other substances in the field. Cut very thin slices from beans, peas, or kernels of corn; mount in water, stain as above directed, and draw as seen under the microscope. Compare with Figs. 7 and 8.[3] Note the fact that the starch is not packed away in the seeds in bulk, but that it is enclosed in little chambers or *cells*.

20. Plant-Cells. — Almost all the parts of the higher plants are built up of little separate portions called *cells*. The cell is the unit of plant-structure, and bears something

[1] At this point the teacher should give a brief illustrated talk on the construction and theory of the compound microscope.

[2] The markings will be seen more distinctly if care is taken not to admit too much light to the object. Rotate the diaphragm beneath the stage of the microscope, or otherwise regulate the supply of light, until the opening is found which gives the best effect.

[3] The differentiation between the starch grains, the other cell-contents, and the cell-walls will appear better in the drawings if the starch grains are sketched with blue ink.

the same relation to the plant of which it is a part that one cell of a honeycomb does to the whole comb. Cells are of all shapes and sizes, from little spheres a ten-thousandth of an inch or less in diameter to slender tubes, such as fibers of cotton, several inches long. To get an idea of the appearance of some rather large cells, scrape a little pulp from a ripe, mealy apple, and examine it first

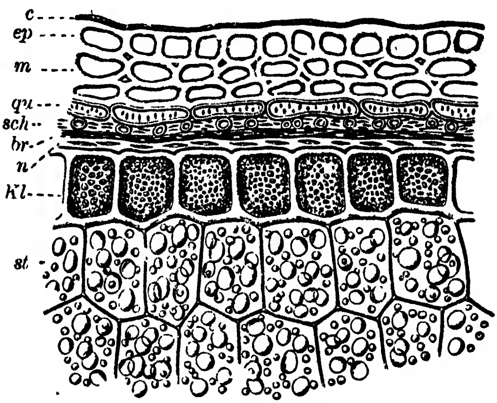


FIG. 8. Section through Exterior Part of a Grain of Wheat.

c, cuticle or outer layer of bran; *ep*, epidermis; *m*, layer beneath epidermis; *qu*, *sch*, layers of hull next to seed-coats; *br*, *n*, seed-coats; *Kl*, layer containing proteid grains; *st*, cells of the endosperm filled with starch. (Greatly magnified.)

with a strong magnifying glass, then with a moderate power of the compound microscope. To see how dead, dry cell-walls with nothing inside them look, examine (as before) a very thin slice of elder pith, sunflower pith, or pith from a dead cornstalk. Look also at the figures in Chapter VII of this book. Notice that the simplest plants (Chapter XXIII) consist of a single cell each. The study

of the structure of plants is the study of the forms which cells and groups of cells assume, and the study of plant physiology is the study of what cells and cell combinations do.

21. Absorption of Starch from the Cotyledons. — Examine with the microscope, using a medium power, soaked beans and the cotyledons from seedlings that have been growing for three or four weeks. Stain the sections with iodine solution, and notice how completely the clusters of starch grains that filled most of the cells of the unsprouted cotyledons have disappeared from the shriveled cotyledons of the seedlings. A few grains may be left, but they have lost their sharpness of outline.

22. Oil. — The presence of oil in any considerable quantity in seeds is not as general as is the presence of starch, though in many common seeds there is a good deal of it.

Sometimes the oil is sufficiently abundant to make it worth while to extract it by pressure, as is done with flaxseed, cotton-seed, the seeds of some plants of the cress family, the "castor bean" and other seeds.

23. Dissolving Oil from Ground Seeds. — It is not easily possible to show a class how oil is extracted from seeds by pressure; but there are several liquids which readily dissolve oils and yet have no effect on starch and most of the other constituents of seeds.

EXPERIMENT VI

Extraction of Oil by Ether or Benzine. — To a few ounces of ground flaxseed add an equal volume of ether or benzine. Let it stand ten or fifteen minutes and then filter. Let the liquid stand in a saucer or evaporating dish in a good draught till it has lost the odor of the ether or benzine.

Describe the oil which you have obtained.

Of what use would it have been to the plant?

If the student wishes to perform this experiment at home for himself, he should bear in mind the following.

Caution. — Never handle benzine or ether near a flame or stove.

A much simpler experiment to find oil in seeds may readily be performed by the pupil at home. Put the material to be studied, *e.g.*, flaxseed meal, corn meal, wheat flour, cotton-seed meal, buckwheat flour, oatmeal, and so on, upon little labeled pieces of white paper, one kind of flour or meal on each bit of paper. Place all the papers, with their contents, on a perfectly clean plate, free from cracks, or on a clean sheet of iron, and put this in an oven hot enough nearly (but not quite) to scorch the paper. After half an hour remove the plate from the oven, shake off the flour or meal from each paper, and note the results, a more or less distinct grease spot showing the presence of oil, or the absence of any stain showing that there was little or no oil in the seed examined.

24. Albuminous Substances. — Albuminous substances or *proteids* occur in all seeds, though often only in small quantities. They have nearly the same chemical composition as white of egg and the curd of milk among animal substances, and are essential to the plant, since the living and growing parts of all plants contain large quantities of proteid material.

Sometimes the albuminous constituents of the seed occur in more or less regular grains (Fig. 8, *Kl*). But much of the proteid material of seeds is not in any form in which it can be recognized under the microscope. One test for its presence is the peculiar smell which it produces in burning. Hair, wool, feathers, leather, and lean meat all produce a well-known sickening smell when scorched or burned, and the similarity of the proteid material in such seeds as the bean and pea to these substances is shown by the fact that scorching beans and similar seeds give off the familiar smell of burnt feathers.

25. Chemical Tests for Proteids. — All proteids (and very few other substances) are turned yellow by nitric acid, and this yellow color becomes deeper or even orange when the yellowish substance is moistened with ammonia. They are also turned yellow by iodine solution.

EXPERIMENT VII

Detection of Proteids in Seeds. — Extract the germs from some soaked kernels of corn and bruise them; soak some wheat-germ meal for a few hours in warm water, or wash the starch out of wheat-flour dough; reserving the latter for use, place it in a white saucer or porcelain evaporating dish and moisten well with nitric acid; examine after fifteen minutes.

26. The Brazil-Nut as a Typical Oily Seed. — Not many familiar seeds are as oily as the Brazil-nut. Its large size makes it convenient for examination, and the fact that this nut is good for human food makes it the more interesting to investigate the kinds of plant-food which it contains.

EXPERIMENT VIII

Testing Brazil-Nuts for Plant-Foods. — Crack fifteen or twenty Brazil-nuts, peel off the brown coating from the kernel of each, and then grind the kernels to a pulp in a mortar. Shake up this pulp with ether, pour upon a paper filter, and wash with ether until the washings when evaporated are nearly free from oil. The funnel containing the filter should be kept covered as much as possible until the washing is finished. Evaporate the filtrate to procure the oil, which may afterwards be kept in a glass-stoppered bottle. Dry the powder which remains on the filter and keep it in a wide-mouthed bottle. Test portions of this powder for proteids and for starch. Explain the results obtained.

27. Other Constituents of Seeds. — Besides the substances above suggested, others occur in different seeds. Some of these are of use in feeding the seedling, others are of value in protecting the seed itself from being eaten by animals or in rendering it less liable to decay. In such seeds as that of the nutmeg, the essential oil which gives it its characteristic flavor probably makes it unpalatable to animals and at the same time preserves it from decay.

Date seeds are so hard and tough that they cannot be eaten and do not readily decay. Lemon, orange, horse-chestnut, and buckeye seeds are too bitter to be eaten, and the seeds of the apple, cherry, peach, and plum are somewhat bitter.

The seeds of larkspur, thorn-apple,[1] croton, the castor-oil plant, nux vomica, and many other kinds of plants contain active poisons.

[1] Datura, commonly called "Jimson weed."

CHAPTER III

MOVEMENTS, DEVELOPMENT, AND MORPHOLOGY OF THE SEEDLING

28. How the Seedling emerges. — As the student has already learned by his own observations, the seedling does not always push its way straight out of the ground. Corn, like all the other grains and grasses, it is true, sends a tightly rolled, pointed leaf vertically upward into the air. But the other seedlings examined usually will not be found to do anything of the sort. The squash seedling is a good one in which to study what may be called the arched hypocotyl type of germination. If the seed when planted is laid horizontally on one of its broad surfaces, it usually goes through some such changes of position as are shown in Fig. 9.

The seed is gradually tilted until at the time of their emergence from the ground the cotyledons are almost vertical. The only part above the ground-line at this period is the arched hypocotyl. Once out of ground, the cotyledons soon rise until they are again vertical, but with the other end up from that which stood highest. Then the two cotyledons separate until they once more lie horizontal, pointing away from each other.

Can you suggest any advantage which the plant derives from having the cotyledons dragged out of the ground rather than having them pushed out, tips first?

29. What pushes the Cotyledons up? — A very little study of any set of squash seedlings is sufficient to show that the portion of the plant where roots and hypocotyl are joined neither rises nor sinks, but that the plant grows both ways from this part. It is evident that as soon as the hypocotyl begins to lengthen much it must do one of two things: either push the cotyledons out into the air or else force the root down into the ground as one might push a stake down. What

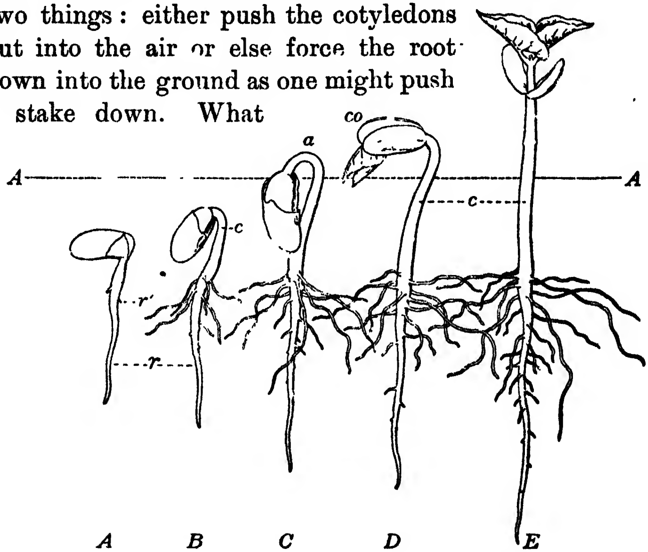


FIG. 9. Successive Stages in the Life History of the Bean Seedling.

AA, the surface of the ground; *r*, primary root; *r′*, secondary root; *c*, hypocotyl; *a*, arch of hypocotyl; *co*, cotyledons.

changes does the plantlet undergo in passing from the stage shown at *A* to that of *B* and of *C*, making it harder and harder for the root to be thrust downward?

30. Use of the Peg. — Squash seedlings usually (though not always) form a sort of knob on the hypocotyl. This

is known as the *peg*. Study a good many seedlings and try to find out what the lengthening of the hypocotyl, between the peg and the bases of the cotyledons, does for the little plant. Set a lot of squash seeds, hilum down, in moist sand or sawdust and see whether the peg is more or less developed than in seeds sprouted lying on their sides, and whether the cotyledons in the case of the vertically planted seeds usually come out of the ground in the same condition as do others.

31. Disposition made of the Cotyledons. — The cotyledons of the squash during the growth of the seedling increase greatly in surface, acquire a green color and a generally leaf-like appearance, and, in fact, do the work of ordinary leaves. In such a case as this the appropriateness of the name *seed-leaf* is evident enough, — one recognizes at sight the fact that the cotyledons are actually the plant's first leaves. In the bean the leaf-like nature of the cotyledons is not so clear. They rise out of the ground like the squash cotyledons, but then gradually shrivel away, though they may first turn green and somewhat leaf-like for a time.

The development of the plumule seems to depend somewhat on that of the cotyledons. The squash seed has cotyledons which are not too thick to become useful leaves, and so the plant is in no special haste to get ready any other leaves. The plumule, therefore, cannot readily be found in the unsprouted seed, and is almost microscopic in size at the time when the hypocotyl begins to show outside of the seed-coats.

32. Root, Stem, and Leaf. — By the time the seedling is well out of the ground it usually possesses the three kinds of *vegetative organs*, or parts essential to growth, of ordinary flowering plants, *i.e.*, the root, stem, and leaf, or, as they

are sometimes classified, root and shoot. All of these organs may multiply and increase in size as the plant grows older, and their mature structure will be studied in later chapters, but some facts concerning them can best be learned by watching their growth from the outset.

33. Elongation of the Root. — We know that the roots of seedlings grow pretty rapidly from the fact that each day finds them reaching visibly farther down into the water or other medium in which they are planted. A sprouted Windsor bean in a vertical thistle-tube will send its root downward fast enough so that ten minutes' watching through the microscope will suffice to show growth. To find out just where the growth goes on requires a special experiment.

EXPERIMENT IX

In what Portions of the Root does its Increase in Length take place? —Sprout some peas on moist blotting paper in a loosely covered tumbler. When the roots are one and a half inches or more long, mark them along the whole length with little dots made with a bristle dipped in water-proof India ink, or a fine inked thread stretched on a little bow of whalebone or brass wire.

Transfer the plants to moist blotting paper under a bell-glass or an inverted battery jar and examine the roots at the end of twenty-four hours to see along what portions their length has increased; continue observations on them for several days.

34. Root-Hairs. — Barley, oats, wheat, red clover, or buckwheat seeds soaked and then sprouted on moist blotting paper afford convenient material for studying *root-hairs.* The seeds may be kept covered with a watch-glass or a clock-glass while sprouting. After they have begun to germinate well care must be taken not to have them

kept in too moist an atmosphere, or very few root-hairs will be formed. Examine with the magnifying glass those parts of the root which have these appendages.

Try to find out whether all the portions of the root are equally covered with hairs, and, if not, where they are most abundant (see also Fig. 10).

The root-hairs in plants growing under ordinary conditions are surrounded by the moist soil and wrap themselves around microscopical particles of earth (Fig. 11). Thus they are able to absorb rapidly through their thin walls the soil-water with whatever mineral substances it has dissolved in it.

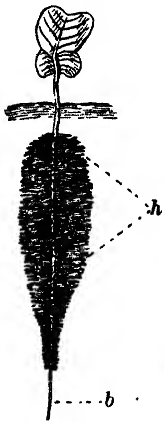
35. The Young Stem. — The hypocotyl, or portion of the stem which lies below the cotyledons, is the earliest formed portion of the stem. Sometimes this lengthens but little, as in Fig. 2; often, however, as the student knows from his own observations, the hypocotyl lengthens enough to raise the cotyledons well above ground, as in Fig. 9.

The later portions of the stem are considered to be divided into successive *nodes* (places at which a leaf, or a scale which represents a leaf, appears) and *internodes* (portions between the leaves).

The student should watch the growth of a seedling bean or pea and ascertain by actual measurements whether the internodes lengthen after they have once been formed, and, if so, for how long a time the increase continues.

36. The First Leaves. — The cotyledons are, as already explained, the first leaves which the seedling possesses, — even if a plumule is found well developed in the seed, it was formed after the cotyledons. In those plants which have so much food stored in the cotyledons as to render these unfit ever to become useful foliage leaves, there is

little or nothing in the color, shape, or general appearance of the cotyledon to make one think it really a leaf, and it is only by studying many cases that the botanist is enabled to class all cotyledons as leaves in their nature, even if they are quite unable to do the ordinary work of leaves. The



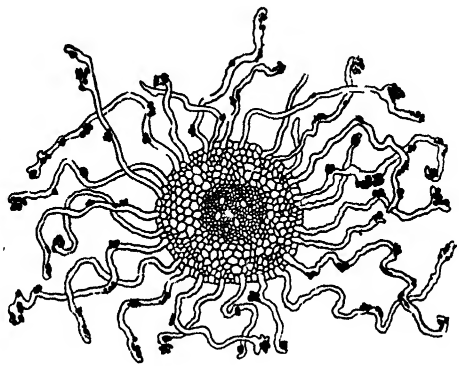


FIG. 10. FIG. 11.

FIG. 10. A Turnip Seedling, with the Cotyledons developed into Temporary Leaves.

h, root-hairs from the primary root; *b*, bare portion of the root on which no hairs have as yet been produced.

FIG. 11. Cross-Section of a Root.

A good deal magnified, showing root-hairs attached to particles of soil, and sometimes enwrapping these particles.

study of the various forms which the parts or organs of a plant may assume is called *morphology;* it traces the relationship of parts which are really akin to each other, though dissimilar in appearance and often in function. In seeds which have endosperm, or food stored outside of the embryo, the cotyledons usually become green and

leaf-like, as they do, for example, in the four-o'clock, the morning-glory, and the buckwheat; but in the seeds of the grains (which contain endosperm) a large portion of the single cotyledon remains throughout as a thickish mass buried in the seed. In a few cases, as in the pea, there are scales instead of true leaves formed on the first nodes above the cotyledons, and it is only at about the third node above that leaves of the ordinary kind appear.

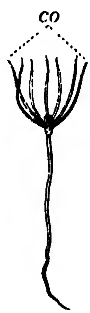


FIG. 12. Germinating Pine.

co, cotyledons.

In the bean and some other plants which in general bear one leaf at a node along the stem there is a pair produced at the first node above the cotyledons, and the leaves of this pair differ in shape from those which arise from the succeeding portions of the stem.

37. Classification of Plants by the Number of their Cotyledons. — In the pine family the germinating seed often displays more than two cotyledons, as shown in Fig. 12; in the majority of common flowering plants the seed contains two cotyledons, while in the lilies, the rushes, the sedges, the grasses, and some other plants there is but one cotyledon. Upon these facts is based the division of most flowering plants into two great groups: the *dicotyledonous plants*, which have two seed-leaves, and the *monocotyledonous plants*, which have one seed-leaf. Other important differences nearly always accompany the difference in number of cotyledons, as will be seen later.

38. Tabular Review of Experiments. — Make out a table containing a very brief summary of the experiments thus far performed, as follows.

Number of Experiment	Object sought	Materials and Apparatus	Operations performed	Results	Inferences

CHAPTER IV

ROOTS[1]

39. Origin of Roots. — The *primary root* originates from the lower end of the hypocotyl, as the student learned from his own observations on sprouting seeds. The branches of the primary root are called *secondary roots*, and the branches of these are known as *tertiary roots*. Those roots which occur on the stem or in other unusual places are known as *adventitious roots*. The roots which form so readily on cuttings of willow, southernwood, tropæolum, French marigold, geranium (pelargonium), tradescantia, and many other plants, when placed in damp earth or water, are adventitious.

40. Aërial Roots. — While the roots of most familiar plants grow in the earth and are known as *soil-roots*, there are others which are formed in the air, called *aërial roots*. They serve various purposes: in some tropical air-plants (Plate I) they serve to fasten the plant to the tree on which it establishes itself, as well as to take in water which drips from branches and trunks above them, so that these plants require no soil and grow in mid-air suspended from trees, which serve them merely as supports;[2] many such

[1] To the plant the root is more important than the stem. The author has, however, treated the structure of the latter more fully than that of the root, mainly because the tissues are more varied in the stem and a moderate knowledge of the more complex anatomy of the stem will serve every purpose.

[2] If it can be conveniently managed, the class will find it highly interesting and profitable to visit any greenhouse of considerable size in which the aërial roots of orchids and aroids may be examined.

Plate I. Aerial Roots of an Orchid.

air-plants are grown in greenhouses. In such plants as the ivy (Fig. 13) the aërial roots (which are also adventitious) hold the plant to the wall or other surface up which it climbs.

In the Indian corn roots are sent out from nodes at some distance above the ground and finally descend until they

FIG. 13. Aërial Adventitious Roots of the Ivy.

enter the ground. They serve both to anchor the cornstalk so as to enable it to resist the wind and to supply additional water to the plant.[1] They often produce no rootlets until they reach the ground.

41. Water-Roots. — Many plants, such as the willow, readily adapt their roots to live either in earth or in water, and some, like the little floating duckweed, regularly produce

[1] Specimens of the lower part of the cornstalk, with ordinary roots and aërial roots, should be dried and kept for class study.

roots which are adapted to live in water only. These water-roots often show large and distinct sheaths on the ends of the roots, as, for instance, in the so-called water-hyacinth. This plant is especially interesting for laboratory cultivation from the fact that it may readily be transferred to moderately damp soil, and that the whole plant presents curious modifications when made to grow in earth instead of water.

42. Parasitic Roots.[1] — The dodder, the mistletoe, and a good many other *parasites* live upon nourishment which they steal from other plants called *hosts*. The parasitic roots, or *haustoria*, form the most intimate connections with the interior portions of the stem or the root, as the case may be, of the host-plant on which the parasite fastens itself.

In the dodder, as is shown in Fig. 14, it is most interesting to notice how admirably the seedling parasite is adapted to the conditions under which it is to live. Rooted at first in the ground, it develops a slender, leafless stem, which, leaning this way and that, no sooner comes into permanent contact with a congenial host than it produces haustoria at many points, gives up further growth in its soil-roots, and grows rapidly on the strength of the supplies of ready-made sap which it obtains from the host.

43. Forms of Roots. — The primary root is that which proceeds like a downward prolongation directly from the lower end of the hypocotyl. In many cases the mature root-system of the plant contains one main root much larger than any of its branches. This is called a *taproot* (Fig. 15).

Such a root, if much thickened, would assume the form shown in the carrot, parsnip, beet, turnip, salsify, or radish, and is called a fleshy root. Some plants produce *multiple*

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. I, pp. 171–213.

primary roots, that is, a cluster proceeding from the lower end of the hypocotyl at the outset. If such roots become thickened, like those of the sweet potato and the dahlia (Fig. 17), they are known as *fascicled roots*.

FIG. 14. Dodder growing upon a Golden-Rod Stem.

s, seedling dodder plants, growing in earth; *h*, stem of host; *r*, haustoria or parasitic roots of dodder; *l*, scale-like leaves; *A*, magnified section of a portion of willow stem, showing penetration of haustoria.

Roots of grass, etc., are thread-like, and known as *fibrous roots* (Fig. 16).

44. General Structure of Roots. — The structure of the very young root can be partially made out by examining the entire root with a moderate magnifying power, since

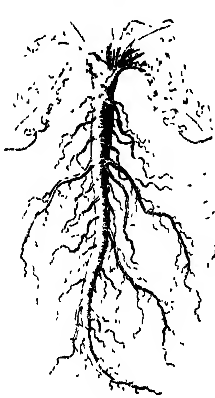


FIG. 15.
A Taproot.

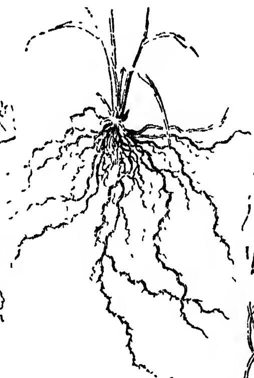


FIG. 16.
Fibrous Roots.

FIG. 17.
Fascicled Roots.

the whole is sufficiently translucent to allow the interior as well as the exterior portion to be studied while the root is still alive and growing. Earth roots will not do for this, since the adhering particles are opaque and hide the structures beneath.

Place some vigorous cuttings of tradescantia or *Zebrina*, which can usually be obtained of a gardener or florist, in a beaker or jar of water.[1] The jar should be as thin and transparent as possible, and it is well to get a flat-sided rather than a cylindrical one. Leave the jar of cuttings in a sunny, warm place. As soon as roots have

[1] If the tradescantia or *Zebrina* cannot be obtained, roots of seedlings of oats, wheat, or barley, or of red-clover seedlings raised in a large covered cell on a microscope slide, may be used.

developed at the nodes and reached the length of three-quarters of an inch or more, arrange a microscope in a horizontal position (see *Handbook*) and examine the tip and adjacent portion of one of the young roots with a power of from twelve to twenty diameters.

Note:

(*a*) The root-cap, of loosely attached cells.

(*b*) The central cylinder.

(*c*) The cortical portion, a tubular part enclosing the solid central cylinder.

(*d*) The root-hairs, which cover some parts of the outer layer of the cortical portion very thickly. Observe particularly how far toward the tip of the root the root-hairs extend, and where the youngest ones are found.

Make a drawing to illustrate all the points above suggested (*a*, *b*, *c*, *d*). Compare your drawing with Fig. 18. Make a careful study of longitudinal sections through the centers of the tips of very young roots of the hyacinth or the Chinese sacred lily. Sketch one section and compare the sketch with Fig. 18.

Make a study of the roots of any of the common duckweeds, growing in a nutrient solution in a jar of water under a bell-glass, and note the curious root-pockets which here take the place of root-caps.

45. Details of Root-Structure. — The plan on which the young root is built has been outlined in Sect. 44. A few further particulars are necessary to an understanding of how the root does its work. On examining Fig. 19, the cylinders of which the root is made up are easily distinguished, and the main constituent parts of each can be made out without much trouble. The epidermis-cells are seen to be somewhat brick-shaped, many of them provided with extensions into root-hairs. Inside the epidermis lie several layers of rather globular, thin-walled cells, and inside these a boundary layer between the cortical or bark portion of the root and the central cylinder. This latter region is especially marked by the presence of certain groups of cells, shown at *w* and *d* and at *b*, the two

former serving as channels for air and water, the latter (and *w* also) giving toughness to the root.

Roots of shrubs and trees more than a year old will be found to have increased in thickness by the process described in Sect. 88, and a section may look quite unlike the young root-section shown in Fig. 19.

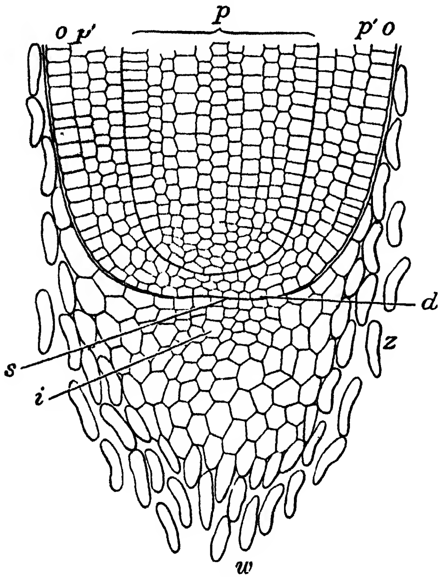


FIG. 18. Lengthwise Section (somewhat diagrammatic) through Root-Tip of Indian Corn. × about 130.

w, root-cap; *i*, younger part of cap; *z*, dead cells separating from cap; *s*, growing point; *o*, epidermis; *p'*, intermediate layer between epidermis and central cylinder; *p*, central cylinder; *d*, layer from which the root-cap originates.

46. Examination of the Root of a Shrub or Tree. — Cut thin transverse sections of large and small roots of any hardwood tree[1] and examine them first with a low power of the microscope, as a two-inch objective, to get the general disposition of the parts, then with a higher power, as the half-inch or quarter-inch, for details. With the low power, note :

(*a*) The brown layer of outer bark.

(*b*) The paler layer within this.

(*c*) The woody cylinder which forms the central portion of the root.

[1] Young suckers of cherry, apple, etc., which may be pulled up by the roots, will afford excellent material.

The distinction between (*b*) and (*c*) is more evident when the section has been exposed to the air for a few minutes and changed somewhat in color.

47. Structure and Contents of a Fleshy Root. — In some fleshy roots, such as the beet, the morphology of the parts is rather puzzling, since they form many layers of tissue in a single season, showing on the cross-section of the root a series of layers which look a little like the annual rings of trees.

The structure of the turnip, radish, carrot, and parsnip is simpler.

Cut a parsnip across a good deal below the middle, and stand the cut end in eosin solution for twenty-four hours.

Then examine by slicing off successive portions from the upper end. Sketch some of the sections thus made. Cut one parsnip lengthwise and sketch the section obtained. In what portion of the root did the colored liquid rise most readily? The ring of red marks the boundary between the cortical portion and the central cylinder. To which does the main bulk of the parsnip belong? Cut thin transverse sections from an ink-stained parsnip and in those sections that show it, find out where

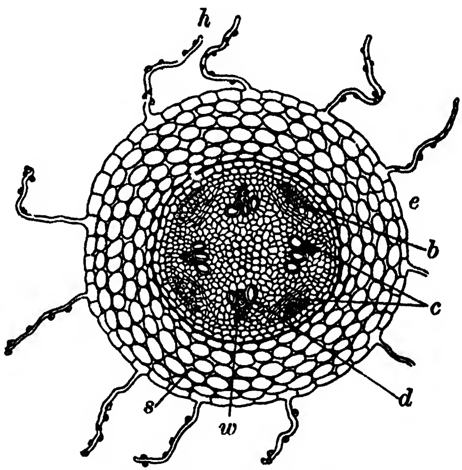


FIG. 19. Much Magnified Cross-Section of a very Young Dicotyledonous Root.

h, root-hairs with adhering bits of sand; *e*, epidermis; *s*, thin-walled, nearly globular, cells of bark; *b*, hard bast; *c*, cambium; *w*, wood-cells; *d*, ducts.

the secondary roots arise. If possible, peel off the cortical portion from one stained root and leave the central cylinder with the secondary roots attached. Stain one section with iodine and sketch it. Where is the starch of this root mainly stored?

Test some bits of parsnip for proteids by boiling them for a minute or two with strong nitric acid.

What kind of plant-food does the taste of cooked parsnips show them to contain? [On no account taste the bits which have been boiled in the poisonous nitric acid.]

48. Storage in Other Roots. — The parsnip is by no means a remarkable plant in its capacity for root-storage. The roots of the yam and the sweet potato contain a good deal of sugar and much more starch than is found in the parsnip. Beet-roots contain so much sugar that a large part of the sugar supply of Europe and an increasing portion of our own supply is obtained from them. Oftentimes the bulk of a fleshy root is exceedingly large as compared with that of the parts of the plant above ground.

A good example of this occurs in a plant,[1] related to the morning-glory and the sweet potato, found in the south-eastern United States, which has a root of forty or fifty pounds weight.

Not infrequently roots have a bitter or nauseous taste, as in the case of the chicory, the dandelion, and the rhubarb, and a good many, like the monkshood, the yellow jasmine, and the pinkroot, are poisonous. Can you give any reason why the plant may be benefited by the disgusting taste or poisonous nature of its roots?

49. Use of the Food stored in Fleshy Roots. — The parsnip, beet, carrot, and turnip are *biennial plants;* that is, they do not produce seed until the second summer or fall after they are planted.

[1] *Ipomœa Jalapa.*

The first season's work consists mainly in producing the food which is stored in the roots. To such storage is due their characteristic fleshy appearance. If this root is planted in the following spring, it feeds the rapidly growing stem which proceeds from the bud at its summit, and an abundant crop of flowers and seed soon follows; while the root, if examined in late summer, will be found to be withered, with its store of reserve material quite exhausted.

The roots of the dahlia (Fig. 17), the sweet potato, and a multitude of other *perennials*, or plants which live for many years, contain much stored plant-food. Many such plants die to the ground at the beginning of winter, and in spring make a rapid growth from the materials laid up in the roots.

50. Extent of the Root-System. — The total length of the roots of ordinary plants is much greater than is usually supposed. They are so closely packed in the earth that only a few of the roots are seen at a time during the process of transplanting, and when a plant is pulled or dug up in the ordinary way a large part of the whole mass of roots is broken off and left behind. A few plants have been carefully studied to ascertain the total weight and length of the roots. Those of winter wheat have been found to extend to a depth of seven feet. By weighing the whole root-system of a plant and then weighing a known length of a root of average diameter, the total length of the roots may be estimated. In this way the roots of an oat plant have been calculated to measure about 154 feet; that is, all the roots, if cut off and strung together end to end, would reach that distance.

51. Absorption of Water by Roots. — Many experiments on the cultivation of corn, wheat, oats, beans, peas, and other familiar plants in water have proved that some plants,

at any rate, can thrive very well on ordinary lake, river, or well water, together with the food which they absorb from the air (Chapter XIII). Just how much water some kinds of plants give off (and therefore absorb) per day will be discussed when the uses of the leaf are studied. For the present it is sufficient to state that even an annual plant during its lifetime absorbs through the roots very many times its own weight of water. Grasses have been known to take in their weight of water in every twenty-four hours of warm, dry weather. This absorption takes place mainly through the root-hairs, which the student has examined as they occur in the seedling plant, and which are found thickly clothing the younger and more rapidly growing parts of the roots of mature plants. Some idea of their abundance may be gathered from the fact that on a rootlet of corn grown in a damp atmosphere, and about $\frac{1}{17}$ inch in diameter, 480 root-hairs have been counted on each hundredth of an inch in length. The walls of the root-hairs are extremely thin, and they are free from any holes or pores which can be seen even by the highest power of the microscope, yet the water of the soil penetrates very rapidly to the interior of the root-hairs. The soil-water brings with it all the substances which it can dissolve from the earth about the plant; and the closeness with which the root-hairs cling to the particles of soil, as shown in Fig. 19, must cause the water which is absorbed to contain more foreign matter than underground water in general does, particularly since the roots give off enough weak acid from their surface to corrode the surface of stones which they enfold or cover.

52. Movements of Young Roots. — The fact that roots usually grow downward is so familiar that we do not

generally think of it as a thing that needs discussion or explanation. Since they are pretty flexible, it may seem as though young and slender roots merely hung down by their own weight, like so many bits of wet cotton twine. But a very little experimenting will answer the question whether this is really the case. Making fine equidistant cross-marks with ink along the upper and the lower surface of a root that is about to bend downward at the tip readily shows that those of the upper series soon come to be farther apart, — in other words, that *the root is forced to bend downward by the more rapid growth of its upper as compared with its under surface.*

53. Direction taken by Secondary Roots. — As the student has already noticed in the seedlings which he has studied, the branches of the primary root usually make a considerable angle with it. Often they run out for long distances almost horizontally. This is especially common in the roots of forest trees, above all in cone-bearing trees, such as pines and hemlocks. This horizontal or nearly horizontal position of large secondary roots is the most advantageous arrangement to make them useful in staying or guying the stem above to prevent it from being blown over by the wind.

54. Fitness of the Root for its Position and Work. — The distribution of material in the woody roots of trees and shrubs and their behavior in the soil show many adaptations to the conditions by which the roots are surrounded. The growing tip of the root, as it pushes its way through the soil, is exposed to bruises; but these are largely warded off by the root-cap. The tip also shows a remarkable sensitiveness to contact with hard objects, so that when touched by one it swerves aside and thus finds it way downward by the easiest path. Roots with an unequal

water supply on either side grow toward the moister soil. Roots are very tough, because they need to resist strong pulls, but not as stiff as stems and branches of the same size, because they do not need to withstand sidewise pressure, acting from one side only. The corky layer which covers the outsides of roots is remarkable for its power of preventing evaporation. It must be of use in retaining in the root the moisture which otherwise might be lost on its way from the deeper rootlets (which are buried in damp soil) through the upper portions of the root-system, about which the soil is often very dry.

55. Propagation by Means of Roots. — Some familiar plants, such as rose bushes, are usually grown from roots or root-cuttings.

Bury a sweet potato or a dahlia root in damp sand and watch the development of sprouts from adventitious buds. One sweet potato will produce several such crops of sprouts, and every sprout may be made to grow into a new plant. It is in this way that the crop is started wherever the sweet potato is grown for the market.

56. Review Summary of Roots.

Kinds of roots as regards origin	
Kinds as regards medium in which they grow .	
Structure of root of a tree.	
Storage in roots	materials. location. uses.
Absorption of water by roots	apparatus. amount.
Movements of roots	nature. causes. uses.

CHAPTER V

PLANT-CELLS; SOME FUNCTIONS OF CELLS IN THE ROOT

57. Structure of a Plant-Cell. — Plants are made up of elementary organs called *cells*. These are small (usually microscopic) objects of many different shapes and subserve various purposes in the life of the plant. The simplest plants of all consist of but a single cell, which may have any one of a great variety of shapes, but is often nearly spherical. The higher plants, such as all the flowering plants, consist of hundreds of thousands or millions of cells each, and the total number in a large tree is inconceivably great.

A single cell taken from the tip of a growing shoot of any of the higher plants, when much magnified, is seen to consist of a cell-wall (*w*, Fig. 20) filled with a more or less liquid substance known as *protoplasm*. A large part of the bulk of this protoplasm consists of a roundish object *n*, called the *nucleus*, and inside this is a more opaque body *nc*, called the *nucleolus*. As the cell grows the protoplasm is soon found to separate

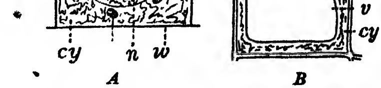


FIG. 20. Two rapidly Growing Cells (both greatly magnified, *A* twice as much as *B*). *A* is a very young cell in which the protoplasm does not as yet show vacuoles. *B* is older, with several vacuoles; *n*, nucleus; *nc*, nucleolus; *cy*, protoplasm or cytoplasm; *v*, vacuoles; *w*, cell-wall.

into mucilaginous or jelly-like portions and watery enclosed droplets known as *vacuoles.* The liquid which constitutes the vacuoles is called *cell-sap.*

The cell-wall is made of a substance called *cellulose,* which is familiar to every one in the form of cotton. A bit of cotton wool is nearly pure cellulose. Chemically it is a very inactive substance, and its main use as a part of the cell is to form a tough covering for it through which liquids can readily soak in or out.

58. Characteristics of Living Protoplasm.[1] — The protoplasm is the active part of every cell and all the work of the plant is done by the cell protoplasm, generally in the higher plants, by the coöperation of many thousands of *protoplasts* (as the little protoplasmic units are called). The remarkable powers which belong to living protoplasm have been summed up as follows.

(1) The power to take up new material into its own substance (*selective absorption*). This is not merely a process of soaking up liquids, as a sponge absorbs water. The protoplasmic lining of a root-hair, for example, selects from the soil-water some substances and rejects others.

(2) The ability to change certain substances into others of different chemical composition (*assimilation* or *metastasis,* Sect. 166). The way in which the stored plant-food of seeds is changed into the materials of the young seedling (Sects. 9, 10) is an example of assimilative action exerted by special cells in and adjoining the embryo. Many other instances occur.

(3) The power to cast off waste or used-up material (*excretion*). Getting rid of surplus water and of oxygen constitutes a very large part of the excretory work of plants.

[1] See Huxley's *Essays,* Vol. I, essay on *The Physical Basis of Life.*

(4) The capacity for growth and the production of off-spring (*reproduction*). These are especially characteristic of living protoplasm. It is true that non-living objects may grow in a certain sense, as an icicle or a crystal of salt or of alum in a solution of its own material does; but growth by the process of taking suitable particles into the interior of the growing substance and arranging them into an orderly structure is possible only in the case of live protoplasm.

(5) The possession of the power of originating movements not wholly and directly caused by any external impulse (*automatic movements*). Such, for instance, are the lashing movements of the cilia of minute plants known as Protococcus, Chapter XXIII.

(6) The power of shrinking or closing up (*contractility*).

(7) Sensitiveness when touched or otherwise disturbed (*irritability*). This is shown by insect-catching leaves (Sect. 140), by the leaves of sensitive plants, and by some parts of certain flowers.

59. Osmosis. — In order to understand the selective absorption which constitutes a large part of the work of the roots of plants it is necessary first to study the phenomenon known as *osmosis*. This is the process by which two liquids separated by membranes pass through the latter and mingle.

It is readily demonstrated by experiments with thin animal or vegetable membranes.

EXPERIMENT X

Osmosis as shown in an Egg. — Cement to the smaller end of an egg a bit of glass tubing about six inches long and about three-sixteenths of an inch inside diameter. Sealing-wax or a mixture of equal parts of beeswax and resin melted together will serve for a cement.

Chip away part of the shell from the larger end of the egg, place it in a wide-mouthed bottle or a small beaker full of water, as shown in Fig. 21, then very cautiously pierce a hole through the upper end of the eggshell by pushing a knitting-needle or wire down through the glass tube.

Watch the apparatus for some hours and note any change in the contents of the tube. Explain.

The rise of liquid in the tube is evidently due to water making its way through the thin membrane which lines the eggshell, although this membrane contains no pores visible even under the microscope.

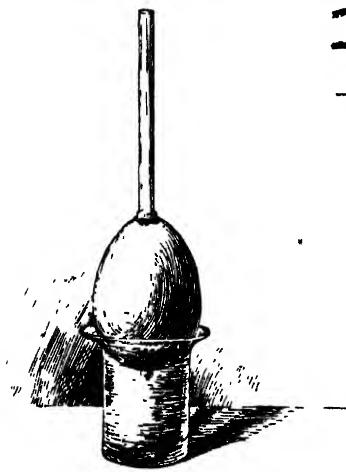


FIG. 21. Egg on Beaker of Water, to show Osmosis.

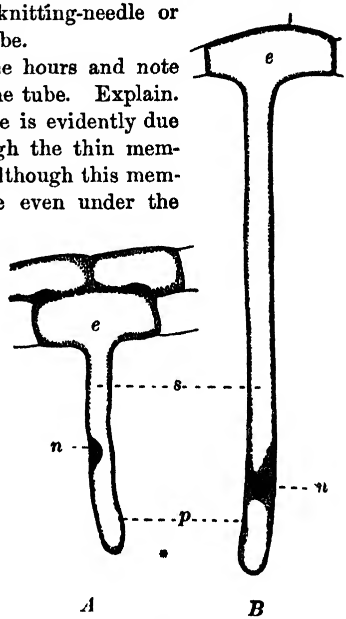


FIG. 22.

A, a very young root-hair; *B*, a much older one (both greatly magnified). *e*, cells of the epidermis of the root; *n*, nucleus; *s*, watery cell-sap; *p*, thicker protoplasm lining the cell-wall.

60. Osmosis in Root-Hairs. — The soil-water (practically identical with ordinary spring or well water) is separated from the more or less sugary or mucilaginous sap inside of the root-hairs only by their delicate cell-walls lined

with a thin layer of protoplasm (Fig. 22). This soil-water will pass rapidly into the plant, while very little of the sap will come out. The selective action, which causes the flow of liquid through the root-hairs to be almost wholly inward, is due to the living layer of protoplasm, which covers the inner surface of the cell-wall of the root-hair. When the student has learned how active a substance protoplasm often shows itself to be, he will not be astonished to find it behaving almost as though it were possessed of intelligence and will. Traveling by osmotic action from cell to cell, a current of water derived from the root-hairs is forced up through the roots and into the stem, just as the contents of the egg was forced up into the tube shown in Fig. 21.

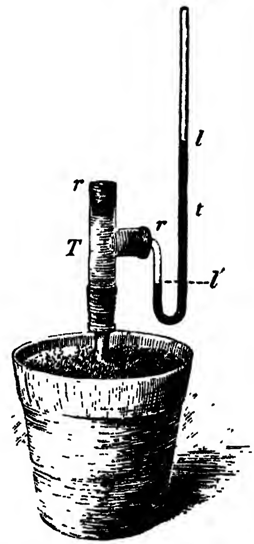


FIG. 23. Apparatus to measure Root-Pressure.

T, large tube fastened to the stump of the dahlia stem by a rubber tube; *r r*, rubber stoppers; *t*, bent tube containing mercury; *l l'*, upper and lower level of mercury in *T*.

61. Root-Pressure. — The force with which the upward-flowing current of water presses may be estimated by attaching a mercury gauge to the root of a tree or the stem of a small sapling. This is best done in early spring after the thawing of the ground but before the leaves have appeared. The experiment may also be performed indoors upon almost any plant with a moderately firm

stem through which the water from the soil rises freely. A dahlia plant or a tomato plant answers well, though the root-pressure from one of these will not be nearly as great as that from a larger shrub or a tree growing out of doors. In Fig. 23 the apparatus is shown attached to the stem of a dahlia. The difference of level of the mercury in the bent tube serves to measure the root-pressure. For every foot of difference in level there must be a pressure of nearly six pounds per square inch on the stump at the base of the tube *T*.[1]

A black-birch root tested in this way at the end of April has given a root-pressure of thirty-seven pounds to the square inch. This would sustain a column of water about eighty-six feet high.

[1] See *Handbook*.

CHAPTER VI

STEMS

62. What the Stem is. — The work of taking in the raw materials which the plant makes into its own food is done mainly by the roots and the leaves. These raw materials are taken from earth, from water, and from the air (see Chapter XIII). The stem is that part or organ of the plant which serves to bring roots and leaves into communication with each other. In most flowering plants the stem also serves the important purpose of lifting the leaves up into the sunlight where alone they can best do their special work.

The student has already, in Chapter III, learned something of the development of the stem and the seedling; he has now to study the external appearance and internal structure of the mature stem. Much in regard to this form and structure can conveniently be learned from the examination of twigs and branches of our common forest trees in their winter condition.

63. The Horse-Chestnut Twig.[1] — Procure a twig of horse-chestnut eighteen inches or more in length. Make a careful sketch of it, trying to bring out the following points.

(1) The general character of the bark.

[1] Where the buckeye is more readily obtained it will do very well. Hickory twigs answer the same purpose, and the latter is a more typical form, having alternate buds. The magnolia or the tulip tree will do. The student should (sooner or later) examine at least one opposite- and one alternate-leaved twig

(2) The large horseshoe-shaped scars and the number and position of the dots on these scars. Compare a scar with the base of a leaf-stalk furnished by the teacher.

(3) The ring of narrow scars around the stem in one or more places,[1] and the different appearance of the bark above and below such a ring. Compare these scars with those left after removing the scales of a terminal bud.

(4) The buds at the upper margin of each leaf-scar and the strong terminal bud at the end of the twig.

(5) The flower-bud scar, a concave impression, to be found in the angle produced by the forking of two twigs, which form, with the branch from which they spring, a Y-shaped figure.

(6) (On a branch larger than the twig handed round for individual study) the place of origin of the twigs on the branch. Make a separate sketch of this.

The portion of stem which originally bore any pair of leaves is called a *node*, and the portions of stem between nodes are called *internodes*.

Describe briefly in writing alongside the sketches any observed facts which the drawings do not show.

If your twig was a crooked, rough-barked, and slow-growing one, exchange it for a smooth, vigorous one, and note the differences. Or if you sketched a quickly grown shoot, exchange for one of the other kind.

Answer the following questions:

(*a*) How many inches did your twig grow during the last summer?
How many in the summer before?
How do you know?
How many years old is the whole twig given you?

(*b*) How were the leaves arranged on the twig?
How many leaves were there?
Were they all of the same size?

(*c*) What has the mode of branching to do with the arrangement of the leaves? with the flower-bud scars?

(*d*) The dots on the leaf-scars mark the position of the bundles of ducts and wood-cells which run from the wood of the branch through the leaf-stalk up into the leaf.

[1] A very vigorous shoot may not show any such ring.

64. Twig of Beech. — Sketch a vigorous young twig of beech (or of hickory, magnolia, tulip tree) in its winter condition, noting particularly the respects in which it differs from the horse-chestnut. Describe in writing any facts not shown in the sketch. Notice that the buds are not opposite, nor is the next one above any given bud found directly above it, but part way round the stem from the position of the first one. Ascertain, by studying several twigs and counting around, which bud is above the first and how many turns round the stem are made in passing from the first to the one directly above it.

Observe with especial care the difference between the beech and the horse-chestnut in mode of branching, as shown in a large branch provided for the study of this feature.

65. Relation of Leaf Arrangement to Branching.[1] — This difference depends on the fact that the leaves of the horse-chestnut were arranged in pairs on opposite sides of the stem, while those of the beech were not in pairs. Since the buds are found at the upper edges of the leaf-scars, and since most of the buds of the horse-chestnut and the beech are leaf-buds and destined to form branches, the mode of branching and ultimately the form of the tree must depend largely on the arrangement of leaves along the stem.

66. Opposite Branching. — In trees, the leaves and buds of which are opposite, the tendency will be to form twigs in four rows about at right angles to each other along the sides of the branch, as shown in Fig. 24.

This arrangement will not usually be perfectly carried out, since some of the buds may never grow, or some may

[1] The teacher in the Eastern and Middle States will do well to make constant use, in the study of branches and buds, of Newell's *Outlines of Lessons in Botany*, Part I. The student can observe for himself, with a little guidance from the teacher, most of the points which Miss Newell suggests. If the supply of material is abundant, the twigs employed in the lessons above described need not be used further, but if material is scanty, the study of buds may at once be taken up. (See also Bailey's *Lessons with Plants*, Part I.)

grow much faster than others and so make the plan of branching less evident than it would be if all grew alike.

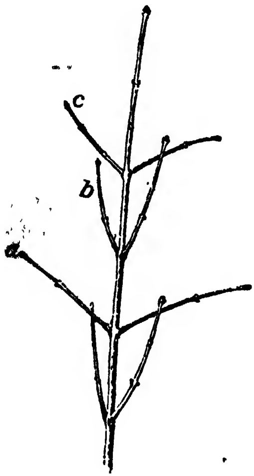


FIG. 24. Opposite Branching in a very Young Sapling of Ash.

67. Alternate Branching. — In trees like the beech the twigs will be found to be arranged in a more or less regular spiral line about the branch. This, which is known as the *alternate* arrangement (Fig. 25), is more commonly met with in trees and shrubs than the *opposite* arrangement. It admits of many varieties, since the spiral may wind more or less rapidly round the stem. In the apple, pear, cherry, poplar, oak, and walnut, one passes over five spaces before coming to a leaf which is over the first, and in doing this it is necessary to make two complete turns round the stem.

FIG. 25. Alternate Branching in a very Young Apple Tree.

68. Growth of the Terminal Bud. — In some trees the terminal bud from the very outset keeps the leading place, and the result of this mode of growth is to produce a slender, upright tree, with an *excurrent* trunk like that of Plate II. In such trees as the apple and many oaks the terminal bud has no preëminence

PLATE II. Excurrent Trunks of European Cypress.

over others, and the form of the tree is round-topped and spreading, *deliquescent* like that in Plate III.

Most of the larger forest trees are intermediate between these extremes.

Branches get their characteristics to a considerable degree from the relative importance of their terminal buds. If these are mainly flower-buds, as is the case in the horse-chestnut, the tree is characterized by frequent forking, and has no long horizontal branches.

If the terminal bud keeps the lead of the lateral ones, but the latter are numerous and most of them grow into

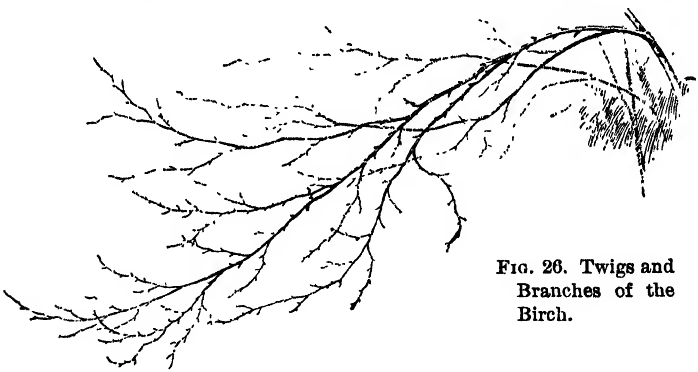


FIG. 26. Twigs and Branches of the Birch.

slender twigs, the delicate spray of the elm and many birches is produced (Fig. 26).

The general effect of the branching depends much upon the angle which each branch or twig forms with that one from which it springs. The angle may be quite acute, as in the birch, or more nearly a right angle, as in the ash (Fig. 24).

It is these differences that help to give to leafless woods in winter their unending variety and beauty.

69. Indefinite Annual Growth. — In most of the forest trees, and in the larger shrubs, the wood of the branches is matured and fully developed during the summer, and protected buds are formed on the twigs to their very tips. In other shrubs — for example, in the sumac, the raspberry, and blackberry — the shoots continue to grow until their soft and partly matured tips are killed by the frost. Such a mode of growth is called *indefinite annual growth*, to distinguish it from the *definite annual growth* of most trees.

70. Trees, Shrubs, and Herbs. — Plants of the largest size, with a main trunk of a woody structure, are called *trees*. *Shrubs* differ from trees in their smaller size, and generally in their more forking and divided stem. The witch-hazel, the dogwoods, and the alders, for instance, are most of them classed as shrubs for this reason, though in height some of them equal the smaller trees. Some of the smallest shrubby plants, like the blueberry, the wintergreen, and the trailing arbutus, are only a few inches in height, but are ranked as shrubs because their woody stems do not die quite to the ground in winter.

Herbs are plants whose stems above ground die every winter.

71. Annual, Biennial, and Perennial Plants. — *Annual* plants are those which live but one year, *biennials* those which live nearly or quite two years.

Some annual plants may be made to live over winter, flowering in their second summer. This is true of winter wheat and rye among cultivated plants.

Perennial plants live for a series of years. Many kinds of trees last for centuries. The Californian giant redwoods, or Sequoias, which reach a height of over 300 feet under favorable circumstances, live nearly 2000 years; and

PLATE III. Deliquescent Trunks of Olive.

some monstrous cypress trees found in Mexico were thought by Professor Asa Gray to be from 4000 to 5000 years old.

72. Stemless Plants. — The so-called *stemless plants*, like the dandelion (Fig. 27) and some violets, are not really stemless at all, but send out their leaves and flowers from a very short stem which hardly rises above the surface of the ground.

FIG. 27. The Dandelion; a so-called Stemless Plant.

Now, as will be shown later (Chapter XXI), plants live subject to a very fierce competition among themselves and exposed to almost constant attacks from animals.

Any plant which can grow in safety under the very feet of grazing animals will be especially likely to make its way in the world, since there are many places where it can flourish while ordinary plants would be destroyed. The bitter, stemless dandelion, which is almost uneatable for most animals, unless cooked, which lies too near the earth to be fed upon by grazing animals, and which bears being trodden on with impunity, is a type of a large class of hardy weeds.

And while plants with long stems find it to their account to reach up as far as possible into the sunlight,

the cinquefoil, the white clover, the dandelion, the spurges, the knot-grass, and hundreds of other kinds of plants have found safety in hugging the ground.

73. Climbing and Twining Stems.[1] — Since it is essential to the health and rapid growth of most plants that they should have free access to the sun and air, it is not strange that many should resort to special devices for lifting themselves above their neighbors. In tropical forests, where the darkness of the shade anywhere beneath the tree-tops is so great that few flowering plants can thrive in it, the climbing plants, or *lianas*, often run like great cables for hundreds of feet before they can emerge into the sunshine above, as those shown in the Frontispiece have probably done. In temperate climates no such remarkable climbers are found, but many plants raise themselves for considerable distances. The principal means to which they resort for this purpose are:

Fig. 28. Coiling of a Tendril of Bryony.

(1) Producing roots at many points along the stem above ground and climbing on suitable objects by means of these, as in the English ivy (Fig. 13).

(2) Laying hold of objects by means of tendrils or *twining* branches or *leaf-stalks* (Figs. 28, 29).

(3) Twining about any slender upright support (Fig. 30).

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. I, p. 669.

74. Tendril-Climbers. — The plants which climb by means of tendrils are very interesting subjects for study, but they cannot usually be managed very well in the schoolroom. Continued observation soon shows that the tips of tendrils sweep slowly about in the air until they come in contact with some object about which they can coil themselves. After the tendril has taken a few turns about its support, the free part of the tendril coils into a spiral and thus draws the whole stem toward the point of attachment, as shown in Fig. 28. Some tendrils are leaves or stipules, others are modified stems.

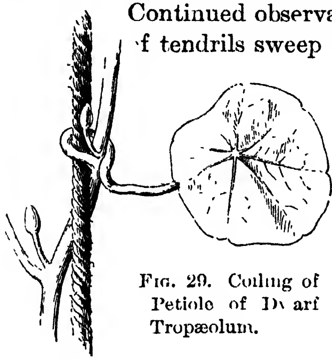


Fig. 29. Coiling of Petiole of Dwarf Tropæolum.

75. Twiners.[1] — Only a few of the upper internodes of the stem of a twiner are concerned in producing the movements of the tip of the stem. This is kept revolving in an elliptical or circular path until it encounters some roughish and not too stout object about which it then proceeds to coil itself. The direction of the coiling varies in different kinds of climbers, some following the course shown in the figure

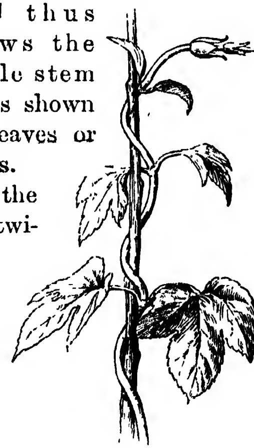


Fig. 30. Twining Stem of Hop.

[1] See article on *Climbing Plants*, by Dr. W. J. Beal, in the *American Naturalist*, Vol. IV, pp. 405–415.

of the hop (Fig. 30); others, as the morning-glory, taking the opposite course.[1]

76. Underground Stems. — Stems which lie mainly or wholly underground are of frequent occurrence and of many kinds.

In the simplest form of *rootstock* (Fig. 31), such as is found in some mints and in many grasses and sedges, the real nature of the creeping underground stem is shown by the presence upon its surface of many scales, which are reduced leaves. Rootstocks of this sort often extend horizontally for long distances in the case of grasses like the sea rye grass, which roots itself firmly and thrives in shifting sand-dunes. In the stouter rootstocks, like that of the iris (Fig. 32) and the

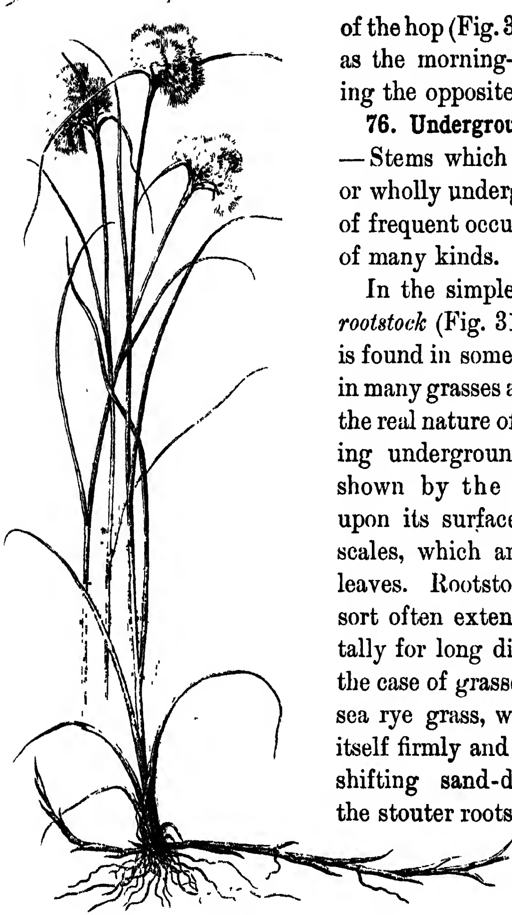


Fig. 31. Rootstock of Cotton-Grass (*Eriophorum*).

[1] See Strasburger, Noll, Schenk, and Schimper, *Text-Book*, pp. 257–260; also Vines, *Students' Text-Book of Botany*, London and New York, 1894, pp. 759, 760.

Caladium, this stem-like character is less evident. The potato is an excellent example of the short and much-thickened underground stem known as a *tuber*.

It may be seen from Fig. 33 that the potatoes are none of them borne on true roots, but only on subterranean branches, which are stouter and more cylindrical than most of the roots. The "eyes" which they bear are rudimentary leaves and buds.

FIG. 32. Roots, Rootstocks, and Leaves of Iris.

Bulbs, whether coated like those of the onion or the hyacinth (Fig. 34), or scaly like those of the lily, are merely very short and stout underground stems, covered with closely crowded scales or layers which represent leaves or the basis of leaves (Fig. 35).

The variously modified forms of underground stems just discussed illustrate in a marked way the storage of nourishment during the winter (or the rainless season, as the case may be) to secure rapid growth during the active season. It is interesting to notice that nearly all of the early flowering herbs in temperate climates, like the crocus, the snowdrop, the spring-beauty, the tulip, and

FIG. 33. Part of a Potato Plant.

The dark tuber in the middle is the one from which the plant has grown.

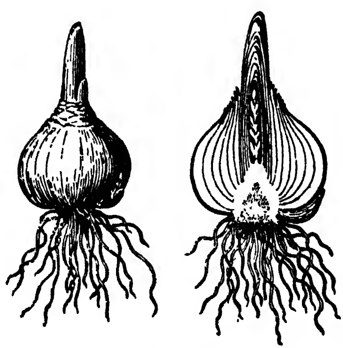


FIG. 34. Bulb of Hyacinth.

Exterior view and split lengthwise.

the skunk-cabbage, owe their early-blooming habit to richly stored underground stems of some kind, or to thick, fleshy roots.

77. Condensed Stems. — The plants of desert regions require, above all, protection from the extreme dryness of the surrounding air, and, usually, from the excessive heat of the sun. Accordingly many desert plants are found quite destitute of ordinary foliage, exposing to the air only a small surface. In the melon-cactuses (Fig. 81) the stem appears reduced to the shape in which the least possible surface is presented by a plant of given bulk, — that is, in a globular form. Other cactuses are more or less cylindrical or prismatic, while still others consist of flattened joints; but all agree in offering much less area to the sun and air than is exposed by an ordinary leafy plant.

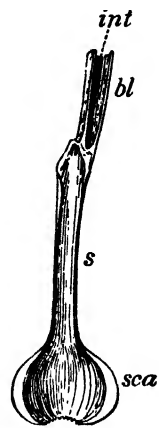


FIG. 35. Longitudinal Section of an Onion Leaf.

sca, thickened base of leaf, forming a bulb-scale; *s*, thin sheath of leaf; *bl*, blade of leaf; *int*, hollow interior of blade.

78. Leaf-like Stems. — The flattened stems of some kinds of cactus (especially the common, showy *Phyllocactus*) are sufficiently like fleshy leaves, with their dark green color and imitation of a midrib, to pass for leaves. There are, however, a good many cases in which the stem takes on a more strikingly leaf-like form. The common asparagus sends up in spring shoots that bear large scales which are really reduced leaves. Later in the season, what seem like thread-like leaves cover the much-branched mature plant, but these green threads are actually

minute branches, which perform the work of leaves (Fig. 36). The familiar greenhouse climber, wrongly known as smilax (properly called *Myrsiphyllum*), bears a profusion of what appear to be delicate green leaves (Fig. 37). Close study, however, shows that these are really short, flattened branches, and that each little branch springs from the

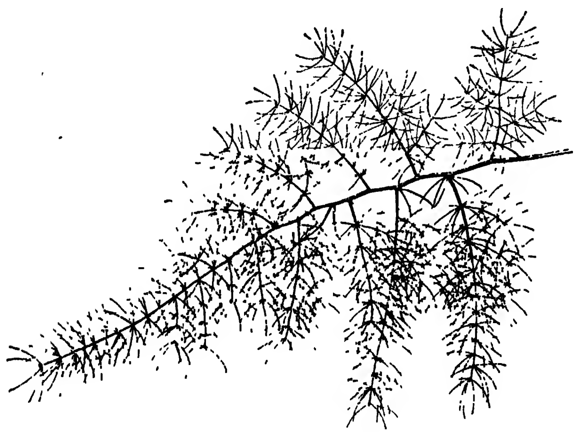


FIG. 36. A Spray of a Common Asparagus (not the edible species).

axil of a true leaf, *l*, in the form of a minute scale. Sometimes a flower and a leaf-like branch spring from the axil of the same scale.

Branches which, like those of *Myrsiphyllum*, so closely resemble leaves as to be almost indistinguishable from them are called *cladophylls*.

79. Modifiability of the Stem. — The stem may, as in the tallest trees in the great lianas of South American forests or the rattan of Indian jungles, reach a length of many hundred feet. On the other hand, in such "stemless"

plants as the primrose and the dandelion, the stem may be reduced to a fraction of an inch in length. It may take on apparently root-like forms, as in many grasses and sedges, or become thickened by underground deposits of starch and other plant-food, as in the iris, the potato, and

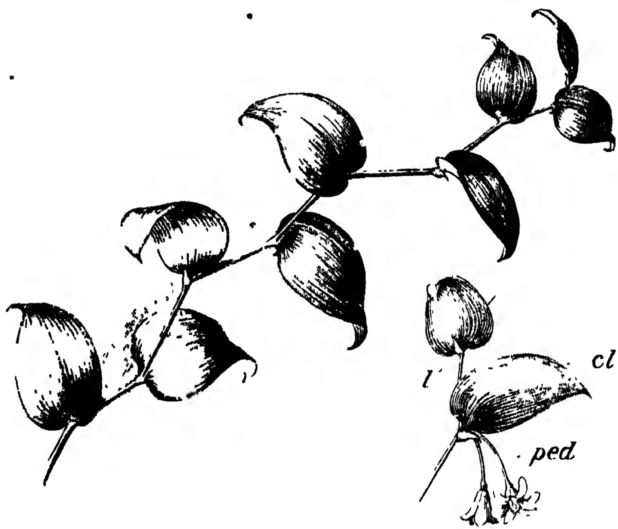


FIG. 37. Stem of "Smilax" (*Myrsiphyllum*).

l, scale-like leaves; *cl*, cladophyll, or leaf-like branch, growing in the axil of the leaf; *ped*, flower-stalk, growing in the axil of a leaf.

the crocus. Condensed forms of stem may exist above ground, or, on the other hand, branches may be flat and thin enough to imitate leaves closely. In short, the stem manifests great readiness in adapting itself to the most varied conditions of existence.

80. Review Summary of Stems.[1]

Kinds of branching due to leaf arrangement	1. 2.
Kinds of tree-trunk due to greater or less predominance of terminal bud	1. 2.
Classes of plants based on amount of woody stem . .	1. 2. 3.
Classes of plants based on duration of life	1. 2. 3.
Various modes of climbing	1. 2. 3.
Kinds of underground stem	1. 2. 3.
Condensed stems above ground	
Leaf-like stems	

[1] Where it is possible to do so, make sketches, where this is not possible, give examples of plants to illustrate the various kinds or classes of plants in the summary.

CHAPTER VII

STRUCTURE OF THE STEM

STEM OF MONOCOTYLEDONOUS PLANTS

81. Gross Structure. — Refer back to the sketches of the corn-seedling to recall something of the early history of the corn-stem. Study the external appearance of a piece of corn-stem or bamboo two feet or more in length. Note the character of the outer surface. Sketch the whole piece and label the enlarged *nodes* and the nearly cylindrical *internodes*. Cut across a corn-stem and examine the cut surface with the magnifying glass. Make some sections as thin as they can be cut and examine with the magnifying glass (holding them up to the light) or with a dissecting microscope. Note the firm rind composed of the epidermis and underlying tissue, the large mass of pith composing the main bulk of the stem, and the many little harder and more opaque spots, which are the cut-off ends of the woody threads known as *fibro-vascular bundles* (Fig. 38, *cv*).

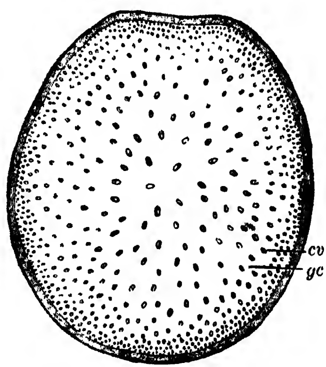


FIG. 38. Diagrammatic Cross-Section of Stem of Indian Corn.

cv, fibro-vascular bundles; *gc*, pithy material between bundles.

Split a portion of the stem lengthwise into thin translucent slices and notice whether the bundles seem to run straight up and down

its length; sketch the entire section × 2. Every fibro-vascular bundle of the stem passes outward through some node in order to connect with some fibro-vascular bundle of a leaf. This fact being known to the student would lead him to expect to find the bundles bending out of a vertical position more at the nodes than elsewhere. Can this be seen in the stem examined?

Observe the enlargement and thickening at the nodes, and split one of these lengthwise to show the tissue within it.

Compare with the corn-stem a piece of palmetto and a piece of cat-brier (*Smilax rotundifolia, S. hispida*, etc.), and notice the similarity of structure, except for the fact that the tissue in the palmetto and the cat-brier, which answers to the pith of the corn-stem, is much darker colored and harder than corn-stem pith. Compare also a piece of rattan and of bamboo.

82. Minute Structure. — Cut a thin cross-section of the corn-stem, examine with a low power of the microscope, and note:

(*a*) The rind (not true bark), composed largely of hard, thick-walled dead cells known as *sclerenchyma* fibers.

(*b*) The fibro-vascular bundles. Where are they most abundant? least abundant?

(*c*) The pith, occupying the intervals between the fibro-vascular bundles.

Study the bundles in various portions of the section and notice particularly whether some are more porous than others. Explain. Sketch some of the outer and some of the inner ones.

A more complicated kind of monocotyledonous stem-structure can be studied to advantage in the surgeons' splints cut from yucca-stems and sold by dealers in surgical supplies.

83. Mechanical Function of the Manner of Distribution of Material in Monocotyledonous Stems. — The well-known strength and lightness of the straw of our smaller grains and of rods of cane or bamboo are due to their form. It can readily be shown by experiment that an iron or steel tube of moderate thickness, like a piece of gas-pipe or of bicycle-tubing, is much stiffer than a solid rod of

Plate IV. Group of Date Palms.

the same weight per foot. The oat straw, the stems of bulrushes, the cane (of our southern canebrakes), and the bamboo are hollow cylinders; the cornstalk is a solid cylinder, but filled with a very light pith. The flinty outer layer of the stalk, together with the closely packed sclerenchyma fibers of the outer rind and the frequent fibro-vascular bundles just within this, are arranged in the best way to secure stiffness. In a general way, then, we may say that the pith, the bundles, and the sclerenchymatous rind are what they are and where they are to serve important mechanical purposes. But they have other uses fully as important.

84. Growth of Monocotyledonous Stems in Thickness. — In most woody monocotyledonous stems, for a reason which will be explained later in this chapter, the increase in thickness is strictly limited. Such stems, therefore, as in many palms and in rattans, are less conical and more cylindrical than the trunks of ordinary trees and are also more slender in proportion to their height.

STEM OF DICOTYLEDONOUS PLANTS

85. Gross Structure of an Annual Dicotyledonous Stem. — Study the external appearance of a piece of sunflower-stem several inches long. If it shows distinct nodes, sketch it. Examine the cross-section and sketch it as seen with the magnifying glass or the dissecting microscope. *After your sketch is finished,* compare it with Fig. 39, which probably shows more details than your drawing, and label the parts shown as they are labeled in that figure. Split a short piece of the stem lengthwise through the center and study the split surface with the magnifying glass. Take a sharp knife or a scalpel and carefully slice and then scrape away the bark until you come to the outer surface of a bundle.

Examine a vegetable sponge (*Luffa*), sold by druggists, and notice that it is simply a network of fibro-vascular bundles. It is the skeleton of a tropical seed-vessel or fruit, very much like that of the wild cucumber common in the Central States, but a great deal larger.

The different layers of the bark cannot all be well recognized in the examination of a single kind of stem. Examine (*a*) the *cork*

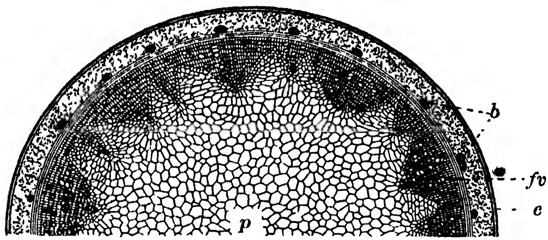


FIG. 39. Diagrammatic Cross-Section of an Annual Dicotyledonous Stem. (Somewhat magnified.)

p, pith; *fv*, woody or fibro-vascular bundles; *e*, epidermis; *b*, bundles of hard bast fibers of the bark.

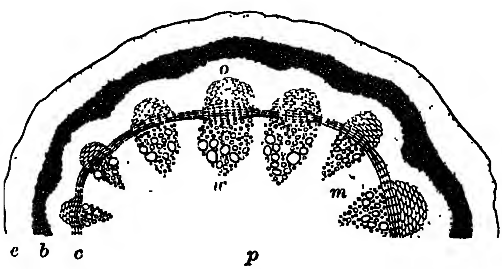


FIG. 40. Diagrammatic Cross-Section of One-Year-Old *Aristolochia* Stem. (Considerably magnified.)

e, region of epidermis; *b*, hard bast; *o*, outer or bark part of a bundle (the cellular portion under the letter); *w*, inner or woody part of bundle; *c*, cambium layer; *p*, region of pith; *m*, a medullary ray. The space between the hard bast and the bundles is occupied by thin-walled, somewhat cubical cells of the bark.

which constitutes the outer layers of the bark of cherry or birch branches two or more years old. Sketch the roundish or oval spongy *lenticels* on the outer surface of the bark. How far in do they extend? Examine (*b*) the *green layer* of bark as shown in twigs or

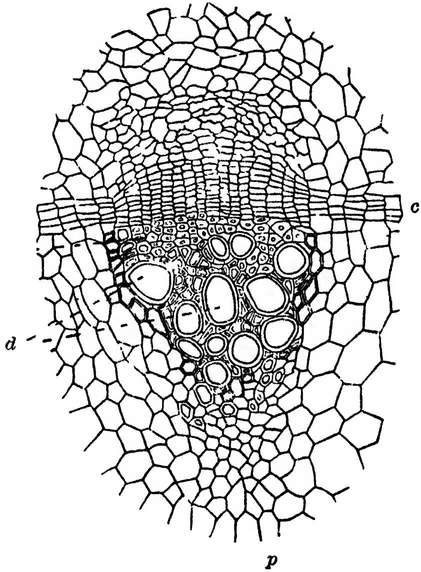


FIG. 41. One Bundle from the Preceding Figure. (× 100.)

w, wood-cells; *d*, ducts. The other letters are as in Fig. 40. Many sieve-cells occur in the region just outside of the cambium of the bundle.

branches of Forsythia, cherry, alder, box-elder, wahoo, or willow. Examine (*c*) the white, fibrous inner layer, known as *hard bast*, of the bark of elm, leatherwood, pawpaw, or basswood.

66. Minute Structure of the Dicotyledonous Stem. — Study, first with a low and then with a medium power of the compound microscope, thin cross-sections of clematis-stem cut just before the end of

the first season's growth.[1] Sketch the whole section without much detail, and then make a detailed drawing of a sector running from center to circumference and just wide enough to include one of the large bundles. Label these drawings in general like Figs. 40, 41.

Note; (*a*) The general outline of the section.
(*b*) The number and arrangement of the bundles. (How many kinds of bundles are there?)
(*c*) The comparative areas occupied by the woody part of the bundle and by the part which belongs to the bark.
(*d*) The way in which the pith and the outer bark are connected (and the bundles separated) by the *medullary rays.*

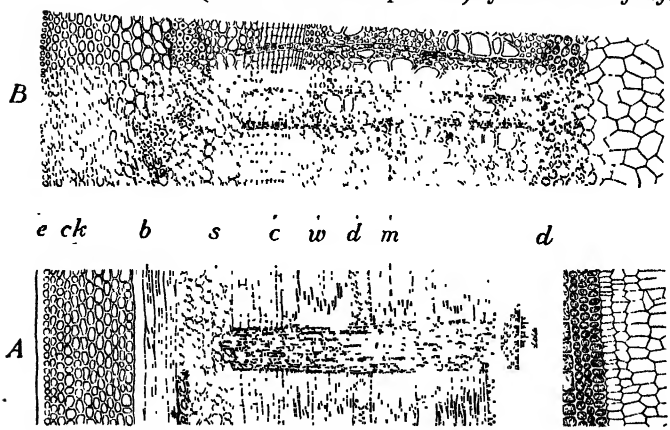


FIG. 42. Stem of Box-Elder One Year Old. (Much magnified.)

A, lengthwise (radial) section; *B*, cross-section. *e*, epidermis; *ck*, cork; *b*, hard bast; *s*, sieve-cells; *c*, cambium; *w*, wood-cells; *m*, medullary rays; *d*, ducts; *p*, pith.

Examine a longitudinal section of the same kind of stem to find out more accurately of what kinds of cells the pith, the bundles, and the outer bark are built. Which portion has cells that are nearly equal in shape, as seen in both sections?

[1] *Clematis virginiana* is simpler in structure than some of the other woody species. *Aristolochia* sections will do very well.

87. The Early History of the Stem. — In the earliest stages of the growth of the stem it consists entirely of thin-walled and rapidly dividing cells. Soon, however, the various kinds of tissue which are found in the full-grown stem begin to appear.

In Fig. 43 the process is shown as it occurs in the castor bean. At *m*, in *B*, is the central column of pith surrounded by eight fibro-vascular bundles, *fv*, each of which contains a number of ducts arranged in a pretty regular manner and surrounded by the forerunners of the true wood-cells.

In *C* the section shows a considerable advance in growth: the fibro-vascular bundles are larger and are now connected by a rapidly growing layer of tissue, *cb*.

As growth continues this layer becomes the *cambium layer*, composed of thin-walled and rapidly dividing cells, as shown in Fig. 45.

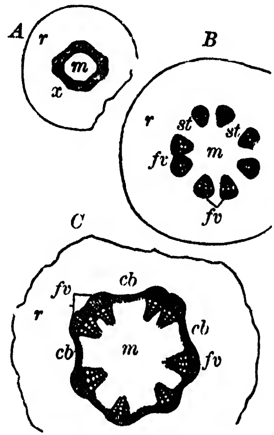


FIG. 43. Transverse Section through the Hypocotyl of the Castor-Oil Plant at Various Stages. (Considerably magnified.)

A, after the root has just appeared outside the testa of the seed; *B*, after the caulicle is nearly an inch long; *C*, at the end of germination; *r*, cortex (undeveloped bark); *m*, pith; *st*, medullary rays; *fv*, fibro-vascular bundles; *cb*, layer of tissue which is to develop into cambium.

88. Secondary Growth. — From the inside of the cambium layer the wood-cells and ducts of the mature stem are produced, while from its outer circumference the new layers of the bark proceed. From this mode of increase the stems of dicotyledonous plants are called *exogenous*, that is, outside-growing. The presence of the cambium layer on the

outside of the wood in early spring is a fact well known to the schoolboy who pounds the cylinder cut from an elder, willow, or hickory branch until the bark will slip off and so enable him to make a whistle. The sweet taste of this pulpy layer, as found in the white pine, the slippery elm, and the basswood, is a familiar evidence of the nourishment which the cambium layer contains.

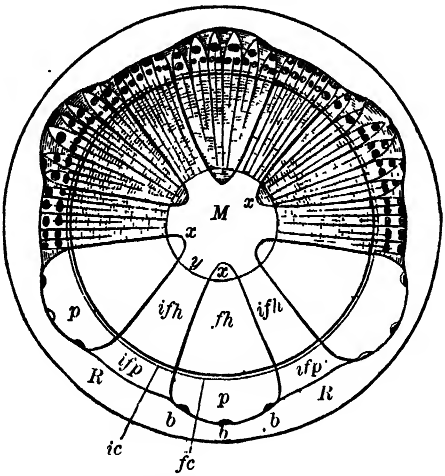


Fig. 44. Diagram to illustrate Secondary Growth in a Dicotyledonous Stem.

R, the first-formed bark; *p*, mass of sieve-cells; *ifp*, mass of sieve-cells between the original wedges of wood; *fc*, cambium of wedges of wood; *ic*, cambium between wedges; *b*, groups of bast-cells; *fh*, wood of the original wedges; *ifh*, wood formed between wedges; *x*, earliest wood formed; *M*, pith.

With the increase of the fibro-vascular bundles of the wood the space between them, which appears relatively large in Fig. 40, becomes less and less, and the pith, which at first extended freely out toward the circumference of the stem, becomes compressed into thin plates so as to form medullary rays.

These are, as already stated, of use in storing the food which the plant in cold and temperate climates lays up in the summer and fall for use in the following spring, and in the very young stem they serve as an important channel for the transference of fluids across the stem from

bark to pith, or in the reverse direction. On account, perhaps, of their importance to the plants, the cells of the medullary rays are among the longest lived of all vegetable cells, retaining their vitality in the beech tree sometimes, it is said, for more than a hundred years.

After the interspaces between the first fibro-vascular bundles have become filled up with wood, the subsequent growth must take place in the manner shown in Fig. 44. The cambium of the original wedges of wood, *fc*, and the cambium, *ic*, formed between these wedges, continues to grow from its inner and from its outer surface, and thus causes a permanent increase in the diameter of the stem and a thickening of the bark, which, however, usually soon begins to peel off from the outside and thus soon attains a pretty constant thickness.

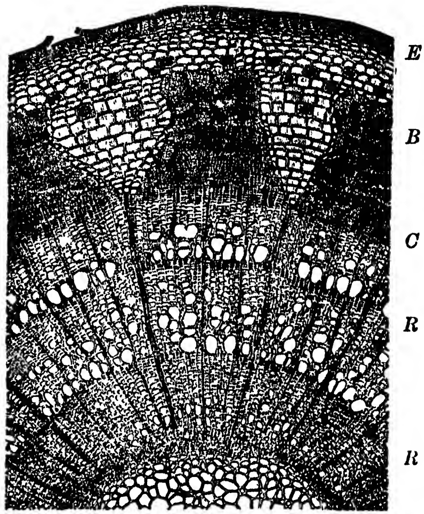


FIG. 45. Cross-Section of a Three-Year-Old Linden Twig. (Much magnified.)

E, epidermis and corky layer of the bark; *B*, bast; *C*, cambium layer; *R*, annual rings of wood.

89. The Dicotyledonous Stem, thickened by Secondary Growth. — Cut off, as smoothly as possible, a small branch of hickory and one of white oak above and below each of the rings of scars already

mentioned (Sect. 63), and count the rings of wood above and below each ring of scars.

How do the numbers correspond? What does this indicate?

Count the rings of wood on the cut-off ends of large billets of some of the following woods: locust, chestnut, sycamore, oak, hickory.

Do the successive rings of the same tree agree in thickness?

Why? or why not?

Does the thickness of the rings appear uniform all the way round the stick of wood? If not, the reason in the case of an upright stem (trunk) is perhaps that there was a greater spread of leaves on the side where the rings are thickest or because there was unequal pressure caused by bending before the wind.

Do the rings of any one kind of tree agree in thickness with those of all the other kinds? What does this show?

In all the woods examined look for:

(*a*) Contrasts in color between the heartwood and the sapwood.[1]

(*b*) The narrow lines running, in very young stems, pretty straight from pith to bark, in older wood extending only a little of the way from center to bark, the *medullary rays* shown in Fig. 42.[2]

(*c*) The wedge-shaped masses of wood between these.

(*d*) The pores which are so grouped as to mark the divisions between successive rings. These pores indicate the cross-sections of *vessels* or *ducts*. Note the distribution of the vessels in the rings to which they belong; compare this with Fig. 45 and decide at what season of the year the largest ducts are mainly produced. Make a careful drawing of the end-section of one billet of wood, natural size.

Cut off a grapevine several years old and notice the great size of the vessels. Examine the smoothly planed surface of a billet of red oak that has been split through the middle of the tree, and note the large shining plates formed by the medullary rays.

Look at another stick that has been planed away from the outside until a good-sized flat surface is shown, and see how the medullary rays are here represented only by their edges.

[1] This is admirably shown in red cedar, black walnut, barberry, black locust, and osage orange.

[2] These and many other important things are admirably shown in the thin wood-sections furnished for $4 per set of 24 by R. B. Hough, Lowville, N.Y.

90. Grafting. — When the cambium layer of any vigorously growing stem is brought in contact with this layer in another stem of the same kind or a closely similar kind of plant, the two may grow together to form a single stem or branch. This process is called *grafting*, and is much resorted to in order to secure apples, pears, etc., of any desired kind (Fig. 46). A twig known as the *scion* from a tree of the chosen variety is grafted on to any kind of tree *of the same species* known as the *stock*, and the resulting stems will bear the wished-for kind of fruit. Often one species is grafted on another, as the pear on the quince or the apple. Rarely trees differing as much as the chestnut and the oak may be grafted together. Sometimes grafting comes about naturally by the branches of a tree chafing against one another until the bark is worn away and the cambium layer of each is in contact with that of the other, or two separate trees may be joined by natural grafting.

FIG. 46. Grafting

At the left scion and stock are shown ready to be united; at the right they are joined and ready to cover with grafting wax.

CHAPTER VIII

LIVING PARTS OF THE STEM; WORK OF THE STEM

91. Active Portions of the Stems of Trees and Shrubs. — In annual plants generally and in the very young shoots of shrubs and trees there are *stomata* or breathing pores which occur abundantly in the epidermis, serving for the admission of air and the escape of moisture, while the green layer of the bark answers the same purpose that is served by the green pulp of the leaf (Chapter XIII). For years, too, the spongy lenticels, which succeed the stomata and occur scattered over the external surface of the bark of trees and shrubs, serve to admit air to the interior of the stem. The lenticels at first appear as roundish spots of very small size, but as the twig or shoot on which they occur increases in diameter the lenticel becomes spread out at right angles to the length of the stem, so that it sometimes becomes a longer transverse slit or scar on the bark, as in the cherry and the birch. But in the trunk of a large tree no part of the bark except the inner layer is alive. The older portions of the bark, such as the highly developed cork of the cork-oak, from which the ordinary stoppers for bottles are made, sometimes cling for years after they are dead and useless except as a protection for the parts beneath against mechanical injuries or against cold. But in many cases, as in the shell-bark hickory and the grapevine, the old bark soon falls off in

strips. The cambium layer is very much alive, and so is the young outer portion of the wood. Testing this sapwood, particularly in winter, when it serves for food storage, shows that it is rich in starch and proteids.

The heartwood of a full-grown tree is hardly living unless the cells of the medullary rays retain their vitality; and so wood of this kind is useful to the tree mainly by giving stiffness to the trunk and larger branches, thus preventing them from being easily broken by storms.

It is, therefore, possible for a tree to flourish, sometimes for centuries, after the heartwood has much of it rotted away and left the interior of the trunk hollow. This is well shown in the trunk of one of the old olive trees of Plate III. In the Sequoias, or big trees of California, there are sometimes cavities large enough to allow a two-horse covered wagon to drive inside; and the "chestnut of a hundred horses" on Mt. Etna gets its name from the fact that the interior cavity would easily hold that number of horsemen. In this case, however, there is some doubt whether the whole was originally a single trunk.

92. Uses of the Components of the Stem. — There is a marked division of labor among the various groups of cells that make up the stem of ordinary dicotyledons, particularly in the stems of trees, and it will be best to explain the uses of the kinds of cells as found in trees rather than in herbaceous plants. A few of the ascertained uses of the various tissues are these:

The pith forms a large portion of the bulk of very young shoots, since it is a part of the tissue of comparatively simple structure amid which the fibro-vascular bundles arise. In mature stems it becomes unimportant, though it often long continues to act as a storehouse of food.

The medullary rays in the young shoot serve as a channel for the transference of water and plant-food in a liquid form across the stem, and they often contain much stored food.

The vessels carry water upward and (sometimes) air downward through the stem.

The wood-cells of the heartwood are useful only to give stiffness to the stem. Those of the sapwood, in addition to this work, have to carry most of the water from the roots to the leaves and other distant portions of the plant.

The cambium layer is the region in which the annual growth of the tree takes place.

The most important portion of the inner bark is that which consists of sieve-tubes, for in these digested and elaborated plant-food is carried from the leaves toward the roots.

The green layer of the bark in young shoots does much toward collecting nutrient substances, or raw materials, and preparing the food of the plant from air and water, but this work may be best explained in connection with the study of the leaf (Chapter XIII).

93. Movement of Water in the Stem. — The student has already learned that large quantities of water are taken up by the roots of plants.

Having become somewhat acquainted with the structure of the stem, he is now in a position to investigate the question as to how the various fluids, commonly known as sap, travel about in it.[1] It is important to notice that sap is by no means the same substance everywhere and at all times. As it first makes its way by osmotic action inward

[1] See the paper on *The So-called Sap of Trees and its Movements*, by Professor Charles R. Barnes, *Science*, Vol. XXI, p. 535.

through the root-hairs of the growing plant it differs but little from ordinary spring water or well water. The liquid which flows from the cut stem of a "bleeding" grapevine, which has been pruned just before the buds have begun to burst in the spring, is mainly water with a little dissolved mucilaginous material. The sap which is obtained from maple trees in late winter or early spring, and is boiled down for syrup or sugar, is still richer in nutritious material than the water of the grapevine, while the elaborated sap which is sent so abundantly into the ear of corn at its period of filling out, or into the growing pods of beans and peas, or into the rapidly forming acorn or the chestnut, contains great stores of food suited to sustain plant or animal life.

EXPERIMENT XI

Rise of Water in Stems. — Cut some short branches from an apple tree or a cherry tree and stand the lower end of each in red ink; try the same experiment with twigs of oak, ash, or other porous wood, and after some hours[1] examine with a magnifying glass and with the microscope, using the 2-inch objective, successive cross-sections of one or more twigs of each kind. Note exactly the portions through which the ink has traveled. Pull off the leaves from one of the stems after standing in the eosin solution, and notice the spots on the leaf-scar through which the eosin has traveled. These spots show the positions of the *leaf-traces*, or fibro-vascular bundles, connecting the stem and the leaf. Repeat with several potatoes cut crosswise through the middle. Try also some monocotyledonous stems, such as those of the lily or asparagus. For the sake of comparison between roots and stems, treat any convenient root, such as a parsnip, in the same way.

[1] If the twigs are leafy and the room is warm, only from 5 to 30 minutes may be necessary.

Examine longitudinal sections of some of the twigs, the potatoes, and the roots. In drawing conclusions about the channels through which the ink has risen (those through which the newly absorbed soil-water most readily travels), bear in mind the fact that a slow soakage of the red ink will take place in all directions, and therefore pay attention only to the strongly colored spots or lines.

What conclusions can be drawn from this experiment as to the course followed by the sap?

From the familiar facts that ordinary forest trees apparently flourish as well after the almost complete decay and removal of their heartwood, and that many kinds will live and grow for a considerable time after a ring of bark extending all round the trunk has been removed, it may readily be inferred that the crude sap in trees must rise through some portion of the newer layers of the wood. A tree girdled by the removal of a ring of sapwood promptly dies.

94. Downward Movement of Liquids. — Most dicotyledonous stems, when stripped of a ring of bark and then stood in water, as shown in Fig. 47, and covered with a bell-jar, develop roots only at or near the upper edge of the stripped portion,[1] and this would seem to prove that such stems send their building material — the elaborated sap — largely at any rate down through the bark. Its course is undoubtedly for the most part through the sieve-cells (Fig. 42), which are admirably adapted to convey liquids. In addition to these general upward and downward movements of sap there must be local transfers laterally through the stem, and these are at times of much importance to the plant.

[1] This may be made the subject of a protracted class-room experiment Strong shoots of willow should be used for the purpose.

Since the liquid building material travels straight down the stem, that side of the stem on which the manufacture of such material is going on most rapidly should grow fastest.

95. Causes of Movements of Water in the Stem. — Some of the phenomena of osmosis were explained in Sect. 60, and the work of the root-hairs was described as due to osmotic action.

Root-pressure (Sect. 61), being apparently able to sustain a column of water only eighty or ninety feet high at the most, and usually less than half this amount, would be quite insufficient to raise the sap to the tops of the tallest trees; some other force or forces must step in to carry it the rest of the way. What these other forces are is still a matter of discussion among botanists.

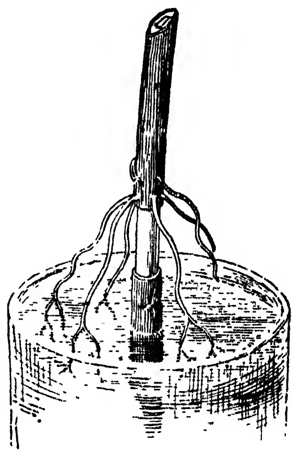


Fig. 47. A Cutting girdled and sending down Roots from the Upper Edge of the Girdled Ring.

The slower inward and downward movement of the sap may be explained as due to osmosis. For instance, in the case of growing wood-cells, sugary sap descending from the leaves into the stem gives up part of its sugar to form the cellulose of which the wood-cells are being made.

This loss of sugar would leave the sap rather more watery than usual, and osmosis would carry it from the growing wood to the leaves, while at the same time a slow transfer of the dissolved sugar will be set up from leaves to wood. The water will be thrown off in the form of vapor as fast as it reaches the leaves, so that they will not

become distended, while the sugar will be changed into cellulose and built into new wood-cells as fast as it reaches the region where such cells are being formed.

Plants in general[1] readily change starch to sugar, and sugar to starch. When they are depositing starch in any part of the root or stem for future use, the withdrawal of sugar from those portions of the sap which contain it most abundantly gives rise to a slow movement of dissolved particles of sugar in the direction of the region where starch is being laid up.

96. Storage of Food in the Stem. — The reason why the plant may profit by laying up a food supply somewhere inside its tissues has already been suggested (Sect. 76).

The most remarkable instance of storage of food in the stem is probably that of sago-palms, which contain an enormous amount, sometimes as much as 800 pounds, of starchy material in a single trunk. But the commoner plants of temperate regions furnish plenty of examples of deposits of food in the stem. As in the case of seeds and roots, starch constitutes one of the most important kinds of this reserve material of the stem, and since it is easier to detect than any other food material which the plant stores, the student will do well to spend time in looking for starch only.

Cut thin cross-sections of twigs of some common deciduous tree or shrub, in its early winter condition, moisten with iodine solution, and examine for starch with a moderately high power of the microscope. Sketch the section with a pencil, coloring the starchy portions with blue ink, used with a mapping pen, and describe exactly in what portions the starch is deposited.

97. Storage in Underground Stems. — The branches and trunk of a tree furnish the most convenient place in which

[1] Not including most of the flowerless and very low and simple kinds.

to deposit food during winter to begin the growth of the following spring. But in those plants which die down to the ground at the beginning of winter the storage must be either in the roots, as has been described in Sect. 49, or in underground portions of the stem.

Rootstocks, tubers, and bulbs seem to have been developed by plants to answer as storehouses through the winter (or in some countries through the dry season) for the reserve materials which the plant has accumulated during the growing season. The commonest tuber is the potato, and this fact and the points of interest which it represents make it especially desirable to use for a study of the underground stem in a form most highly specialized for the storage of starch and other valuable products.

98. A Typical Tuber: the Potato. — Sketch the general outline of a potato, showing the attachment to the stem from which it grew.[1]

Note the distribution of the "eyes," — are they opposite or alternate? Examine them closely with the magnifying glass and then with the lowest power of the microscope. What do they appear to be?

If the potato is a stem, it may branch, — look over a lot of potatoes to try to find a branching specimen. If such a one is secured, sketch it.

Note the little scale overhanging the edge of the eye and see if you can ascertain what this scale represents.

Cut the potato across and notice the faint broken line which forms a sort of oval figure some distance inside the skin.

Place the cut surface in eosin solution, allow the potato to stand there for many hours, and then examine, by slicing off pieces parallel to the cut surface, to see how far and into what portions the solution has penetrated. Refer to the notes on the study of the parsnip (Sect. 47) and see how far the behavior of the potato treated with eosin solution agrees with that of the parsnip so treated.

[1] Examination of a lot of potatoes will usually discover specimens with an inch or more of attached stem.

Cut a thin section at right angles to the skin and examine with a high power. Moisten the section with iodine solution and examine again.

If possible, secure a potato which has been sprouting in a warm place for a month or more (the longer the better), and look near the origins of the sprouts for evidences of the loss of material from the tuber.

EXPERIMENT XII

Use of the Corky Layer. — Carefully weigh a potato, then pare another larger one, and cut portions from it until its weight is made approximately equal to that of the first one. Expose both freely to the air for some days and reweigh. What does the result show in regard to the use of the corky layer of the skin?

99. Morphology of the Potato. — It is evident that in the potato we have to do with a very greatly modified form of stem. The corky layer of the bark is well represented, and the loose cellular layer beneath is very greatly developed; wood is almost lacking, being present only in the very narrow ring which was stained by the red ink, but the pith is greatly developed and constitutes the principal bulk of the tuber. All this is readily understood if we consider that the tuber, buried in and supported by the earth, does not need the kinds of tissue which give strength, but only those which are well adapted to store the requisite amount of food.

100. Structure of a Bulb; the Onion. — Examine the external appearance of the onion and observe the thin membranaceous skin which covers it. This skin consists of the broad sheathing bases of the outer leaves which grew on the onion plant during the summer. Remove these and notice the thick scales (also formed from bases of leaves as shown in Fig. 35) which make up the substance of the bulb.

Make a transverse section of the onion at about the middle and sketch the rings of which it is composed. Cut a thin section from the interior of the bulb, examine with a moderate power of the microscope, and note the thin-walled cells of which it is composed.

Split another onion from top to bottom and try to find:

(*a*) The *plate* or broad flattened stem inside at the base (Fig. 34).

(*b*) The central bud.

(*c*) The bulb-scales.

(*d*) In some onions (particularly large, irregular ones) the bulblets or side buds arising in the axes of the scales near the base.

Test the cut surface for starch.

101. Plant-Foods in the Onion. — *Grape sugar* is an important substance among those stored for food by the plant. It received its name from the fact that it was formerly obtained for chemical examination from grapes. Old, dry raisins usually show little masses of whitish material scattered over the skin which are nearly pure grape sugar. Commercially it is now manufactured on an enormous scale from starch by boiling with diluted sulphuric acid. In the plant it is made from starch by processes as yet imperfectly understood, and another sugar, called *maltose*, is made from starch in the seed during germination.

It may be readily shown by suitable experiments that the onion contains both grape sugar and proteids.

102. Tabular Review of Experiments. — [Continue the table from Sect. 38.]

103. Review Summary of Work of Stem.

Channels for upward movement of water	in young dicotyledonous stems. in dicotyledonous stems several years old. in monocotyledonous stems.
Channels for downward movement of water	in dicotyledonous stems. in monocotyledonous stems.
Channels for transverse movements.	
Storage of plant-food	where stored. kinds stored. uses.

CHAPTER IX

BUDS

104. Structure of Buds.— While studying twigs in their winter condition, as directed in Sects. 63, 64, the student had occasion to notice the presence, position, and arrangement of buds on the branch, but he was not called upon to look into the details of their structure. The most natural time to do this is just before the study of the leaf is begun, since leafy stems spring from buds, and the rudiments of leaves in some form must be found in buds.

105. The Horse-Chestnut Bud. — Examine one of the lateral buds on a twig in its winter or early spring condition.[1]

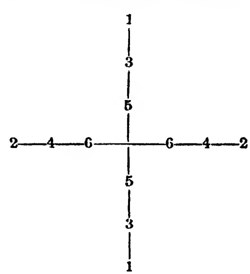
Make a sketch of the external appearance of the buds as seen with a magnifying glass.

How do the scales with which it is covered lie with reference to those beneath them?

Notice the sticky coating on the scales.

Are the scales opposite or alternate?

Remove the scales in pairs, placing them in order on a sheet of paper, thus:



Make the distance from 1 to 1 as much as 6 or 8 inches.

How many pairs are found?

[1] The best possible time for this examination is just as the buds are beginning to swell slightly in the spring. The bud of buckeye or of cottonwood will do for this examination, though each is on a good deal smaller scale than the horse-chestnut bud. Buds may be forced to open early by placing twigs in water in a very warm, light place for many weeks.

Observe as the scales are removed whether the sticky coating is thicker on the outside or the inside of each scale, and whether it is equally abundant on all the successive pairs.

What is the probable use of this coating?

Note the delicate veining of some of the scales as seen through the magnifying glass. What does this mean?

Inside the innermost pair are found two forked woolly objects; what are these?

Compare with Figs. 48 and 55.

Their shape could be more readily observed if the woolly coating were removed.

Can you suggest a use for the woolly coating?

Examine a terminal bud in the same way in which you have just studied the lateral bud.

Does it contain any parts not found in the other?

What is the appearance of these parts?

What do they represent?

If there is any doubt about their nature, study them further on a horse-chestnut tree during and immediately after the process of leafing out in the spring.

For comparison study at least one of the following kinds of buds in their winter or early spring condition: hickory, butternut, beech, ash, magnolia (or tulip tree), lilac, balm of Gilead, cottonwood, cultivated cherry.[1]

Fig. 48. Dissected Bud of Buckeye (*Æsculus macrostachya*), showing Transitions from Bud-Scales to Leaves.

[1] Consult the account of the mode of studying buds in Professor W. F. Ganong's *Teaching Botanist*, pp. 208–210. If some of the buds are studied at home, pupils will have a better chance to examine at leisure the unfolding process.

106. Nature of Bud-Scales. — The fact that the bud-scales are in certain cases merely imperfectly developed leaves or leaf-stalks is often clearly manifest from the series of steps connecting the bud-scale on the one hand with the young leaf on the other, which may be found in many opening buds, as illustrated by Fig. 48. In other buds the scales are not imperfect leaves, but the little appendages (*stipules*, Figs. 63, 64), which occur at the bases of leaves. This kind of bud-scale is especially well shown in the magnolia and the tulip tree.

107. Naked Buds. — All of the buds above mentioned are *winter buds*, capable of living through the colder months of the year, and are scaly buds.

In the herbs of temperate climates, and even in shrubs and trees of tropical regions, the buds are often *naked*, that is, nearly or quite destitute of scaly coverings (Fig. 49).

Make a study of the naked buds of any convenient herb, such as one of the common "geraniums" (*Pelargonium*), and record what you find in it.

108. Position of Buds. — The distinction between *lateral* and *terminal* buds has already been alluded to.

The plumule is the first terminal bud which the plant produces. Lateral buds are usually *axillary*, as shown in Fig. 58, that is, they grow in the angle formed by

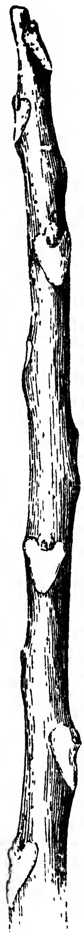


FIG. 49. Tip of Branch of *Ailanthus* in Winter Condition, showing very Large Leaf-Scars and nearly Naked Buds.

the leaf with the stem (Latin *axilla*, armpit). But not infrequently there are several buds grouped in some way about a single leaf-axil, either one above the other, as in the butternut (Fig. 51), or grouped side by side, as in the red maple, the cherry, and the box-elder (Fig. 50).

In these cases all the buds except the axillary one are called *accessory* or *supernumerary* buds.

109. Leaf-Buds and Flower-Buds; the Bud an Undeveloped Branch. — Such buds as the student has so far examined for himself are not large enough to show in the most obvious way the relation of the parts and their real nature.

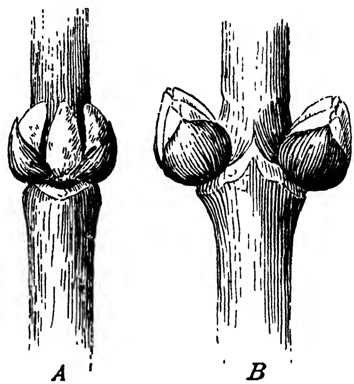


Fig. 50. Accessory Buds of Box-Elder (*Negundo*). (Magnified.)

A, front view of group; *B*, two groups seen in profile.

Fortunately, it is easy to obtain a gigantic terminal bud which illustrates perfectly the structure and arrangement of the parts of buds in general.

Examine and sketch a rather small, firm cabbage, preferably a red one, which has been split lengthwise through the center [1] and note:

(*a*) The short, thick, conical stem.

(*b*) The crowded leaves which arise from the stem, the lower and outer ones largest and most mature, the upper and innermost ones the smallest of the series.

(*c*) The axillary buds found in the angles made by some leaves with the stem.

Compare the section of the cabbage with Fig. 55.

[1] Half of a cabbage will be enough for the entire division.

Most of the buds so far considered were *leaf-buds*, that is, the parts inside of the scales would develop into leaves, and their central axes into stems; but some were *mixed buds*, that is, they contained both leaves and flowers in an undeveloped condition.

FIG. 51. Accessory Buds of Butternut (Reduced.)

l, leaf-scar; *ax*, axillary bud; *a*, *a′*, accessory buds; *t*, terminal bud.

Flower-buds contain the rudiments of flowers only.

Sometimes, as in the black walnut and the butternut, the leaf-buds and flower-buds are readily distinguishable by their difference in form, while in other cases, as in the cultivated cherry, the difference in form is but slight.

The rings of scars about the twig, shown in Fig. 54, mark the place where the bases of bud-scales were attached. A little examination of the part of the twig which lies outside of this ring will lead one to the conclusion that this portion has all grown in the one spring and summer since the bud-scales of that particular ring dropped off. Following out this suggestion, it is easy to reckon the age of any moderately old portion of a branch, since it is equal to the number of segments between the rings. In rapidly growing shoots of willow, poplar, and similar trees, 5 or 10 feet of the length may be the growth of a single year, while in the lateral twigs of the hickory, apple, or cherry the yearly increase may be but a fraction of an inch. Such fruiting

FIG. 52.

A, a pear leaf-bud in autumn; *B* a leafy shoot derived from *A*, as seen in the middle of the following summer, with flower-bud at tip; *C*, the fruit-spur, *B*, in autumn, after the fall of the leaves.

FIG. 53. Fruit-Bud of Pear (same as *C*, of Fig. 52), showing its Development.

A, opening in spring; *B*, later, developing flowers and leaves; *C*, later still: only one flower has produced a fruit, the rest having fallen off. Below it is a lateral bud which will continue the spur next year.

"spurs" as are shown in Fig. 52 are of little use in the permanent growth of the tree, and poplars, elms, soft maples, and other trees shed the oldest of these every year. Whatever the amount of this growth, it is but the lengthening out and development of the bud, which may be regarded as an undeveloped stem or branch, with its internodes so shortened that successive leaves seem almost to spring from the same point. In Figs. 52, 53 the complete history of a fruit-spur of the pear is shown, from the leaf-bud which produced it to the pear which it bears.

Fig. 54. A Slowly Grown Twig of Cherry, Three Inches Long and about Ten Years Old.

The pointed bud, *l*, is a leaf-bud; the more obtuse accessory buds, *f*, *f*, are flower-buds.

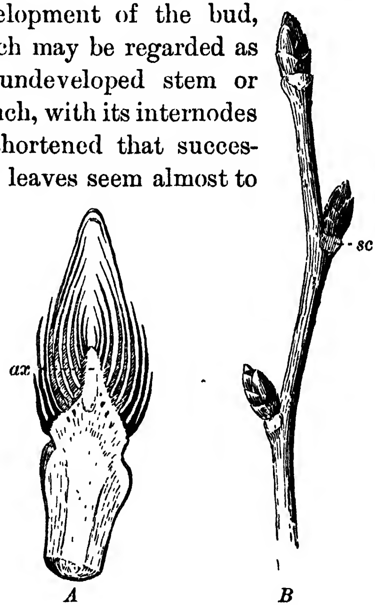


Fig. 55.

B, a twig of European elm; *A*, a longitudinal section of the buds of *B* (considerably magnified). *ax*, the axis of the bud which will elongate into a shoot; *sc*, leaf-scars.

110. Vernation. — Procure a considerable number of buds which are just about to burst and others which have begun to open. Cut each across with a razor or very sharp scalpel; examine first with

the magnifying glass and then with the lowest power of the microscope. Pick to pieces other buds of the same kinds under the magnifying glass, and report upon the manner in which the leaves are packed away.

The arrangement of leaves in the bud is called *vernation;* some of the principal modes are shown in Fig. 56.

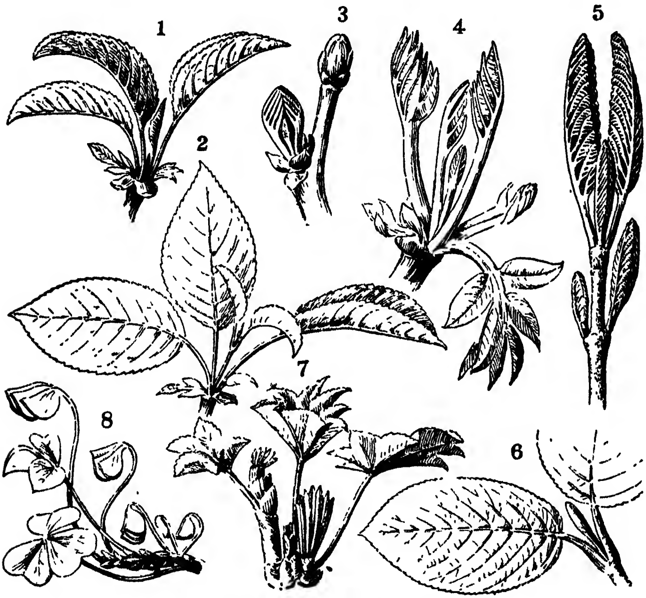


FIG. 56. Types of Vernation.

1, 2, cherry; 3, 4, European walnut; 5, 6, snowball; 7, lady's mantle; 8, oxalis.

In the cherry the two halves of the leaf are folded together flat, with the under surfaces outward; in the walnut the separate *leaflets*, or parts of the leaf, are folded flat and then grouped into a sort of cone; in the snowball

each half of the leaf is plaited in a somewhat fan-like manner, and the edges of the two halves are then brought round so as to meet; in the lady's mantle the fan-like plaiting is very distinct; in the wood sorrel each leaflet is folded smoothly, and then the three leaflets are packed closely side by side. All these modes of vernation and many others have received accurate descriptive names by which they are known to botanists.

111. Importance of Vernation. — The significance of vernation is best understood by considering that there are two important purposes to be served: the leaves must be

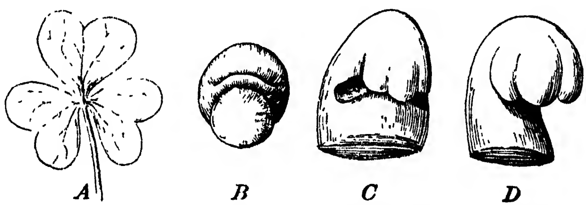


Fig. 57. Development of an Oxalis Leaf.

A, full-grown leaf; *B*, rudimentary leaf, the leaflets not yet evident; *C*, more advanced stage, the leaflets appearing, *D*, a still more advanced stage. (*B*, *C*, and *D* considerably magnified.)

stowed as closely as possible in the bud, and upon beginning to open they must be protected from too great heat and dryness until they have reached a certain degree of firmness. It may be inferred from Fig. 56 that it is common for very young leaves to stand vertically. This protects them considerably from the scorching effect of the sun at the hottest part of the day. Many young leaves, as, for instance, those of the silver-leafed poplar, the pear, the beech, and the mountain ash, are sheltered and protected from the attacks of small insects by a coating of

wool or down which they afterwards lose. Those of the tulip tree are enclosed for a little time in thin pouches, which serve as bud-scales, and are thus entirely shielded from direct contact with the outside air.

112. Dormant Buds. — Generally some of the buds on a branch remain undeveloped in the spring, when the other buds are beginning to grow, and this inactive condition may last for many seasons. Finally the bud may die, or some injury to the tree may destroy so many other buds as to leave the dormant ones an extra supply of food, and this, with other causes, may force them to develop and to grow into branches.

Sometimes the tree altogether fails to produce buds at places where they would regularly occur. In the lilac the terminal bud usually fails to appear, and the result is constant forking of the branches.

113. Adventitious Buds. — Buds which occur in irregular places, that is, not terminal nor in or near the axils of leaves, are called *adventitious buds;* they may spring from the roots, as in the silver-leafed poplar, or from the sides of the trunk, as in our American elm. In many trees, for instance willows and maples, they are sure to appear after the trees have been cut back. Willows and poplars are thus cut back or *pollarded*, as shown in Plate V, in order to cause them to produce a large crop of slender twigs suitable for basket-making or for withes.

Leaves rarely produce buds, but a few kinds do so when they are injured. Those of the bryophyllum, a plant allied to the garden live-for-ever, when they are removed from the plant while they are still green and fresh, almost always send out buds from the margin. These do not appear at random but are borne at the

notches in the leaf-margin and are accompanied almost from the first by minute roots.

Pin up a bryophyllum leaf on the wall of the room or lay it on the surface of moist earth, and follow day by day the formation and development of the buds which it may produce.

This plant seems to rely largely upon leaf-budding to reproduce itself, for in a moderately cool climate it rarely flowers or seeds, but drops its living leaves freely, and from each such leaf one or several new plants may be produced.

114. Review Summary of Chapter IX.

Buds	Coverings.	
	Contents . . .	leaf-buds.
		flower-buds.
		mixed buds.

Classes of buds as regards position	regular .
	irregular.

Make a sketch of Fig. 58 as it looked in June of the same summer; also as it would look the following June (Fig. 58 represents the autumn condition). Sketch the twigs of Fig. 24 and Fig. 25 as seen one year later.

Plate V. Pollarded Poplars.

CHAPTER X

LEAVES

115. The Elm Leaf. — Sketch the leafy twig of elm that is supplied to you.[1] Report on the following points:

(*a*) How many rows of leaves?

(*b*) How much overlapping of leaves when the twig is held with the upper sides of the leaves toward you? Can you suggest a reason for this? Are the spaces between the edges of the leaves large or small compared with the leaves themselves?

Pull off a single leaf and make a very

FIG. 58. Leafy Twig of Poplar

[1] Any elm will answer the purpose. Young strong shoots which extend horizontally are best, since on these leaves are most fully developed and their distribution along the twig appears most clearly. Other good kinds of leaves with which to begin the study, if elm leaves are not available, are those of beech, oak, willow, peach, cherry, apple. Most of the statements and directions above given would apply to any of the leaves just enumerated. If this chapter is reached too early in the season to admit of suitable material being procured for the study of leaf arrangement, that topic may be omitted until the leaves of forest trees have sufficiently matured.

careful sketch of its under surface, about natural size. Label the broad expanded part the *blade*, and the stalk by which it is attached to the twig, *leaf-stalk* or *petiole*.

Study the outline of the leaf and answer these questions:

(*a*) What is the shape of the leaf taken as a whole? (See Appendix.) Is the leaf *bilaterally symmetrical*, *i.e.*, is there a middle line running through it lengthwise, along which it could be so folded that the two sides would precisely coincide?

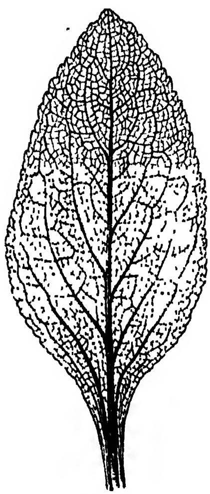


FIG. 59. Netted Veining (pinnate) in Leaf of Foxglove.

(*b*) What is the shape of the tip of the leaf? (See Appendix.)

(*c*) Shape of the base of the leaf? (See Appendix.)

(*d*) Outline of the margin of the leaf? (See Appendix.)

Notice that the leaf is traversed lengthwise by a strong *midrib* and that many so-called *veins* run from this to the margin. Are these veins parallel? Hold the leaf up towards the light and see how the main veins are connected by smaller *veinlets*. Examine with your glass the leaf as held to the light and make a careful sketch of portions of one or two veins and the intersecting veinlets. How is the course of the veins shown on the upper surface of the leaf?

Examine both surfaces of the leaf with the glass and look for hairs distributed on the surfaces. Describe the manner in which the hairs are arranged.

The various forms of leaves are classed and described by botanists with great minuteness,[1] not simply for the study of leaves themselves, but also because in classifying and describing plants the characteristic forms of the leaves of many kinds of plants form a very simple and ready means of distinguishing them from each other and

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. I, pp. 623–637.

identifying them. The student is not expected to learn the names of the several shapes of leaves as a whole or of their bases, tips, or margins, except in those cases in which he needs to use and apply them.

Many of the words used to describe the shapes of leaves are equally applicable to the leaf-like parts of flowers.

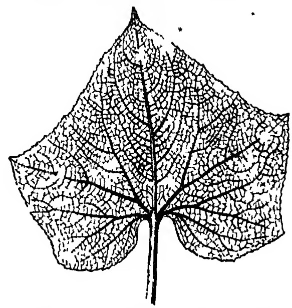


FIG. 60. Netted Veining (palmate) in Leaf of Melon.

116. The Maple Leaf. — Sketch the leafy twig.

Are the leaves arranged in rows like those of the elm? How are they arranged?

How are the petioles distorted from their natural positions to bring the proper surface of the leaf upward toward the light?

Do the edges of these leaves show larger spaces between them than the elm leaves did, *i.e.*, would a spray of maple intercept the sunlight more or less perfectly than a spray of elm? Pull off a single leaf and sketch its lower surface, about natural size.

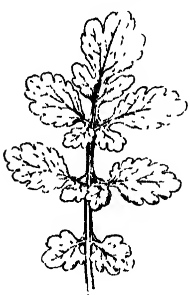


FIG. 61. Pinnately Divided Leaf of Celandine.

The blade of the leaf is discontinuous, consisting of several portions, between which are spaces in which one part of the blade has been developed.

Of the two main parts whose names have already been learned (blade and petiole), which is more developed in the maple than in the elm leaf?

Describe:

(*a*) The shape of the maple leaf as a whole. To settle this, place the leaf on paper, mark the positions of the extreme points, and connect these by a smooth line.

(*b*) Its outline as to main divisions; of what kind and how many?

(*c*) The detailed outline of the margin. (See Appendix.)

Compare the mode of veining or venation of the elm and the maple leaf by making a diagram of each.

These leaves agree in being *netted-veined, i.e.,* in having veinlets that join each other at many angles, so as to form a sort of delicate lace-work, like Figs. 59 and 60.

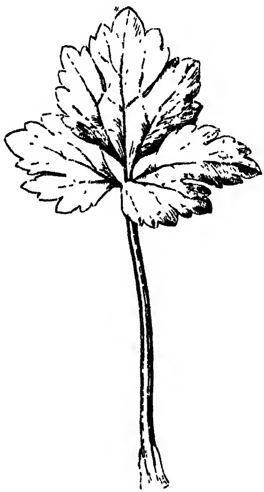


FIG. 62. Palmately Divided Leaf of Buttercup.

They differ, however, in the arrangement of the principal veins. Such a leaf as that of the elm is said to be feather-veined, or *pinnately veined.*

The maple leaf, or any leaf with closely similar venation, is said to be *palmately veined.* Describe the difference between the two plans of venation.

117. Relation of Venation to Shape of Leaves.—As soon as the student begins to observe leaves somewhat widely, he can hardly fail to notice that there is a general relation between the plan of venation and the shape of the leaf. How may this relation be stated? In most cases the principal veins follow at the outset a pretty straight course, a fact for which the student ought to be able to give a reason after he has performed Exp. XVI.

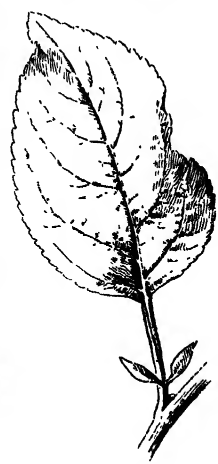


FIG. 63. Leaf of Apple, with Stipules.

On the whole, the arrangement of the veins seems to be such as to stiffen the leaf most in the parts that need most support, and to reach the region near the margin by as short a course as

possible from the end of the petiole, to distribute water quickly throughout.

118. Stipules. — Although they are absent from many leaves and disappear early from others, *stipules* form a part of what the botanist regards as an ideal or model leaf.[1] When present they are sometimes found as little bristle-shaped objects at the base of the leaf, as in the apple leaf (Fig. 63), sometimes as leaf-like bodies, for example in the pansy (Fig. 64), and in many other forms, one of which is that of spinous appendages, as shown in the common locust (Fig. 68).

Fig. 64. Leaf of Pansy, with Leaf-like Stipules.

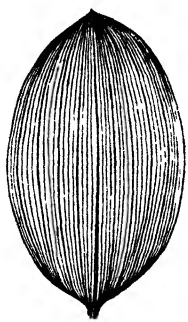


Fig. 65. Parallel-Veined Leaf of Solomon's Seal.

119. Parallel-Veined Leaves. — The leaves of many great groups of plants, such as the lilies, the sedges, and the grasses, are commonly *parallel-veined*, that is, with the veins running nearly parallel, lengthwise through the blade, as shown in Fig. 65, or with parallel

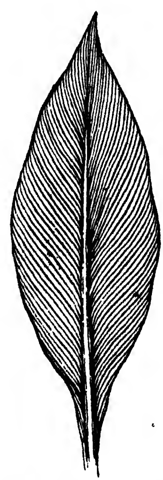


Fig. 66. Parallel Veining in Canna. Veins running from midrib to margin.

[1] Unless the elm twigs used in the previous study were cut soon after the unfolding of the leaves in spring, the stipules may not have been left in any recognizable shape.

veins proceeding from a midrib and thence extending to the margin, as shown in Fig. 66.

120. Occurrence of Netted or Parallel Veining. — The student has already, in his experiments on germination, had an opportunity to observe the difference in mode of veining between the leaves of some dicotyledonous plants and those of monocotyledonous plants. This unlikeness is general throughout these great groups of flowering plants. What is the difference?

Fig. 67. The Fall of the Horse-Chestnut Leaf.

The polycotyledonous pines, spruces, and other coniferous trees have leaves with but a single vein, or two or three parallel ones, but in their case the veining could hardly be other than parallel, since the needle-like leaves are so narrow that no veins of any considerable length could exist except in a position lengthwise of the leaf.

The fact that a certain plan of venation is found mainly in plants with a particular mode of germination, of stem structure, and of arrangement of floral parts, is but one

of the frequent cases in botany in which the structures of plants are correlated in a way which is not easy to explain. No one knows why plants with two cotyledons should have netted-veined leaves, but many such facts as this are familiar to every botanist.

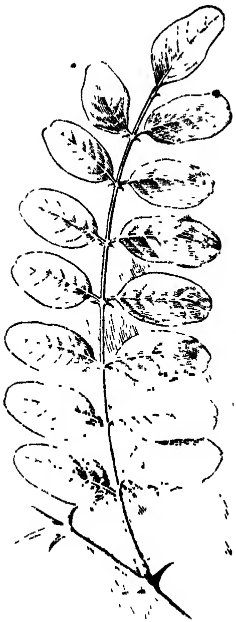


Fig. 68. Pinnately Compound Leaf of Locust, with Spines for Stipules.

121. Simple and Compound Leaves. — The leaves so far studied are *simple leaves*, that is, leaves of which the blades are more or less entirely united into one piece. But while in the elm the margin is cut in only a little way, in some maples it is deeply cut in toward the bases of the veins. In some leaves the gaps between the adjacent portions extend all the way down to the petiole (in palmately veined leaves) or to the midrib (in pinnately veined ones). Such divided leaves are shown in Figs. 61 and 62.

Fig. 69. Pinnately Compound Leaf of Pea. A tendril takes the place of a terminal leaflet.

In still other leaves, known as *compound leaves*, the petiole, as shown in Fig. 67 (*palmately compound*), or the midrib, as shown in Fig. 68 (*pinnately compound*), bears what look to be separate

leaves. These differ in their nature and mode of origin from the portions of the blade of a divided leaf. One result of this difference appears in the fact that some time before the whole leaf is ready to fall in autumn, the leaflets of a compound leaf are seen to be jointed at their attachments. In Fig. 67 the horse-chestnut leaf is shown at the time of falling, with some of the leaflets already disjointed.

That a compound leaf, in spite of the joints of the separate leaflets, is really only one leaf is shown: (1) by the absence of buds in the axils of leaflets (see Fig. 68); (2) by the horizontal arrangement of the blades of the leaflets, without any twist in their individual leaf-stalks; (3) by the fact that their arrangement on the midrib does not follow any of the systems of leaf arrangement on the stem (Sect. 124). If each leaflet of a compound leaf should itself become compound, the result would be to produce a *twice compound* leaf. Fig. 77 shows that of an acacia.

123. Review Summary of Leaves.[1]

Parts of a model leaf	1. 2. 3.
Classes of netted-veined leaves	1. 2.
Classes of parallel-veined leaves	1. 2.
Relation of venation to number of cotyledons	
Compound leaves; types dependent on arrangement of leaflets	1. 2.
Once, twice, or three times compound	

[1] Illustrate by sketches if possible.

CHAPTER XI

ECOLOGY OF LEAVES

123. Ecology. — Plant *ecology* includes all that portion of botany which has to do with the way in which plants get on with their animal and plant neighbors, and especially the way in which they adjust themselves to the nature of the soil and climate in which they live. Ecology, in short, discusses the relations of plants to their surroundings or environment. A good deal of what has been said in previous chapters about such topics as variation of roots for life in air or water, parasitic plants, the occurrence of winter bud-scales, is really ecological botany, although it is not so designated in the sections where it occurs.

124. Leaf Arrangement.[1] — As has been learned from the study of the leafy twigs examined, leaves are quite generally arranged so as to secure the best possible exposure to the sun and air. This, in the vertical shoots of the elm, the oak (Fig. 70), the apple, beech, and other alternate-leaved trees, is not inconsistent with their spiral arrangement of the leaves around the stem. In horizontal twigs and branches of the elm, the beech (Fig. 71), the chestnut, the linden, and many other trees and shrubs, the desired effect is secured by the arrangement of all the leaves in two flat rows, one on each side of the twig. The rows are produced, as it is easy to see on examining such a

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. I, pp. 396–424.

leafy twig, by a twisting about of the petioles. The adjustment in many opposite-leaved trees and shrubs consists in having each pair of leaves cover the spaces between the pair below it, and sometimes in the lengthening of the lower petioles so as to bring the blades of the lower leaves outside those of the upper leaves. Examination of Figs. 72 and 73 will make the matter clear.

FIG. 70. Leaf Arrangement of the Oak.

The student should not fail to study the leafage of several trees of different kinds on the growing tree itself, and in climbers on walls, and to notice how circumstances modify the position of the leaves. Maple leaves, for example, on the ends of the branches are arranged much like those of the horse-chestnut, but they are found to be arranged more nearly flatwise along the inner portions of the branches, that is, the portions nearer the tree. Figs. 74 and 75 show the remarkable difference in arrangement in different branches of the Deutzia, and equally interesting modifications may be found in alternate-leaved trees, such as the elm and the cherry.

FIG. 71. Leaf Arrangement of European Beech.

125. Leaf-Mosaics. — In very many cases the leaves at the end of a shoot are so arranged as to form a rather symmetrical pattern, as in the horse-chestnut (Fig. 72). When this is sufficiently regular,

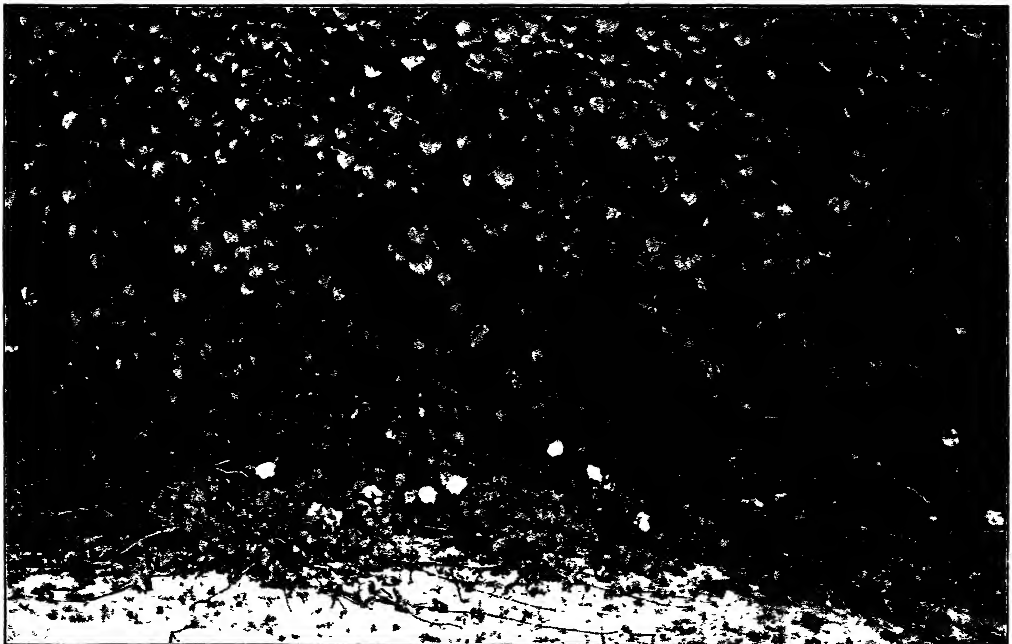


Plate VI. Exposure to Sunlight, Morning-Glory.

usually with the space between the leaves a good deal smaller than the areas of the leaves themselves, it is called a *leaf-mosaic.* Many of the most interesting leaf-groups of this sort (as in the figure above mentioned) are found in the so-called root-leaves of plants. Good examples of these are the dandelion, chicory, fall dandelion, thistle, hawk-weed, pyrola, and plantain. How are the leaves of these plants kept from shading each other?

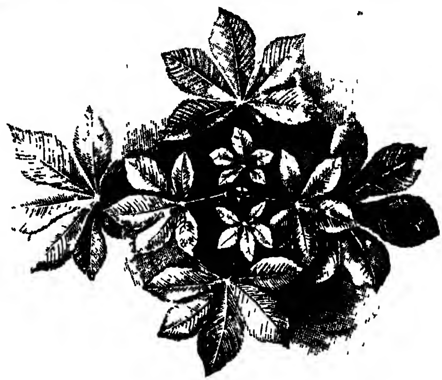


FIG. 72. Leaf Arrangement of Horse-Chestnut on Vertical Shoots (top view).

FIG. 73. Leaf Arrangement of Horse-Chestnut on Vertical Shoots (side view).

126. Much-Divided Leaves. — Not infrequently leaves are cut into slender fringe-like divisions, as in the carrot, tansy, southernwood, wormwood, yarrow, dog-fennel, cypress-vine, and many other common plants. This kind of leaf seems to be adapted to offer considerable surface to

the sun without cutting off too much light from other leaves underneath. Such a leaf is in much less danger of being torn by severe winds than are broader ones with undivided margins. The same purposes are served by compound leaves with very many small leaflets, such as those of the honey-locust, mimosa acacia (Fig. 77), and

FIG. 74. Opposite Leaves of Deutzia[1] (from the same shrub as Fig. 75), as arranged on a Horizontal Branch.

other trees and shrubs of the pea family. What kind of shade is produced by a horse-chestnut or a maple tree compared with that of a honey-locust or an acacia?

127. Daily Movements of Leaves. — Many compound leaves have the power of changing the position of their leaflets to accommodate themselves to varying conditions of light and temperature. Some plants have the power of directing the leaves or leaflets edgewise towards the sun during the hottest parts of the day, allowing them to

[1] *Deutzia crenata.*

extend their surfaces more nearly in a horizontal direction during the cooler hours.

The so-called "sleep" of plants has long been known, but this subject has been most carefully studied rather recently. The wood sorrel, or oxalis, the common bean, clovers, and the locust tree are some of the most familiar of the plants whose leaves assume decidedly different positions at night from those which they occupy during the day. Sometimes the leaflets rise at night, and in many instances they droop, as in the red clover (Fig. 76) and the acacia (Fig. 77).

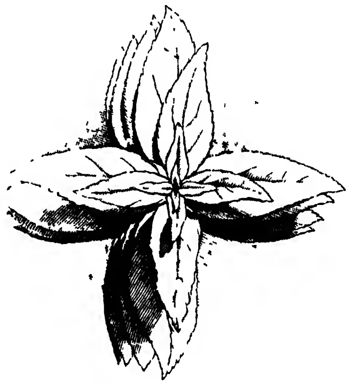


FIG. 75. Opposite Leaves of Deutzia, as arranged on a Vertical Branch.

One useful purpose, at any rate, that is served by the leaf's taking the nocturnal position is protection from frost. It has been proved experimentally that when part of the leaves on a plant are prevented from assuming the folded position, while others are allowed to do so, and the plant is then exposed during a frosty night, the folded ones may escape while the others are killed. Since many plants in tropical climates fold their leaves at night, it is certain

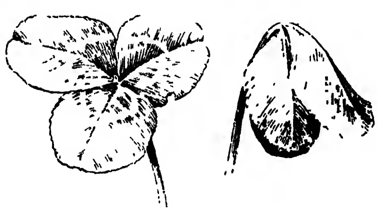


FIG. 76. A Leaf of Red Clover.

At the left, leaf by day; at the right, the same leaf asleep at night.

that this movement has other purposes than protection from frost, and probably there is much yet to be learned about the uses of leaf movements.

128. Vertically Placed Leaves.—Very many leaves, like those of the iris (Fig. 32), always keep their principal surfaces nearly vertical, thus receiving the morning and evening sun upon their faces, and the noonday sun (which is so intense as to injure them when received full on the

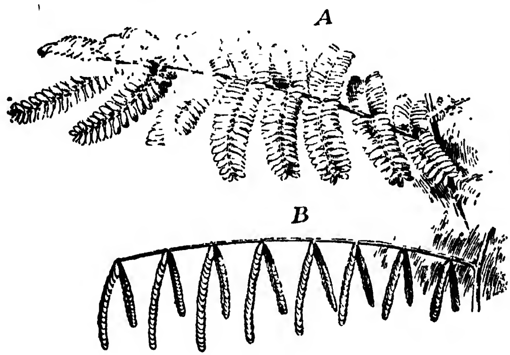


FIG. 77. A Leaf of Acacia.

A, as seen by day; *B*, the same leaf asleep at night.

surface) upon their edges. This adjustment is most perfect in the compass-plant of the prairies of the Mississippi basin. Its leaves stand very nearly upright, many with their edges just about north and south (Fig. 78), so that the rays of the midsummer sun will, during every bright day, strike the leaf-surfaces nearly at right angles during a considerable portion of the forenoon and afternoon, while at midday only the edge of each leaf is exposed to the sun.

A *B*

FIG. 78. Leaves standing nearly Vertical in Compass-Plant (*Silphium laciniatum*).

A, view from east or west; *B*, from north or south.

129. Movements of Leaves and Stems toward or away from Light (Heliòtropic Movements). — The student doubtless learned from his experiments with seedling plants that their stems tend to seek light. The whole plant

above ground usually bends toward the quarter from which the strongest light comes. Such movements are called *heliotropic* from two Greek words which mean turning toward the sun. How do the plants in a window behave with reference to the light?

EXPERIMENT XIII

How do Young Shoots of English Ivy bend with Reference to Light? — Place a thrifty potted plant of English ivy before a small window, *e.g.*, an ordinary cellar window, or in a large covered box painted dull black within and open only on the side toward a south window. After some weeks note the position of the tips of the shoots. Explain the use of their movements to the plant.

130. Positive and Negative Heliotropic Movements; how produced. — Plants may bend either toward or away from the strongest light. In the former case they are said to show *positive heliotropism*, in the latter *negative heliotropism*. In both cases the movement is produced by unequal growth brought about by the unequal lighting of different sides of the stem. If the less strongly lighted side grows faster, what kind of heliotropism results? If the more strongly lighted side grows faster, what kind of heliotropism results? How would a plant behave if placed on a revolving table before a window and slowly turned during the hours of daylight?

131. Review Summary of Chapter XI.

Leaf arrangement	for vertical twigs. for horizontal twigs.
Movements of leaves	Uses of.
Compass-plants.	
Heliotropic bending of stems .	positive. negative.

CHAPTER XII

ECOLOGY OF LEAVES (*continued*)

132. Plant Societies. — A little observation is enough to show the beginner in botany that plants are not scattered indiscriminately over the surface of the earth, but that hills, meadows, fresh-water marshes, salt marshes, and many other kinds of localities have their characteristic asssemblages of plants. Any such group is called a *plant society*. It may consist of only a few species, but more commonly comprises several score or even a hundred or more of flowering plants (seed-plants) alone, not to speak of the multitudes of lower forms, such as ferns, mosses, and simpler microscopic plants.

It will generally be found that the members of a plant society are growing under what is, for them, nearly the best environment, since they cannot usually be made to exchange places with each other. If a square mile of land in Louisiana were to be planted with Minnesota species, and a square mile in Minnesota with Louisiana species, it is very improbable that either tract, if left to itself, would long retain its artificial flora. To this rule there are, however, important exceptions.

133. Ecological Classification of Plants. — The ordinary classification of plants is based, as far as possible, on their actual relationships to each other. But when plants are classified ecologically they are grouped according to their

relations to the world about them. They may, therefore, be gathered into as many (or more than as many) different groups as there are important factors influencing their modes of life. We may classify plants as light-loving and darkness-loving, as requiring free oxygen and not requiring it, and so on.

The most important consideration in classifying seed-plants on ecological grounds is based on their requirements in regard to water. Grouped with reference to this factor in their life, all plants may be classed as:

(1) *Hydrophytes*, or water-loving plants.
(2) *Xerophytes*, or drought-loving (or perhaps drought-tolerating) plants.
(3) *Mesophytes*, or plants which thrive best with a moderate supply of water.

These three classes do not fully express all the relations of plants to the water supply, so two others are found convenient.

(4) *Tropophytes*, or seasonal plants which are hydrophytes during part of the year and xerophytes during another part.[1]
(5) *Halophytes*, or salt-marsh plants and "alkali" plants, species which can flourish in a very saline soil.

134. Leaves in Relation to Ecological Classes.—Although the roots and stems of plants which belong to extremely specialized ecological types offer many modifications which adapt them to the kind of life which they have to lead, yet the leaves are still more important in their adaptations. A good botanist can often decide merely by looking at the

[1] The plants which E. Warming, one of the foremost authorities, classes as mesophytes are many of them grouped by another great authority, A. F. W. Schimper, as tropophytes.

Plate VII. A Cat-Tail Swamp.

leaf of an unknown plant whether it is an alpine, a desert, or a seaside species. This is because of the importance of leaves in disposing of the water taken into the plant (Chapter XIII).

135. Leaves of Hydrophytes.—Not nearly all hydrophytes are aquatics, but some merely prefer very moist soil or moist air. Of the truly aquatic species some have their leaves wholly submerged; others, such as the duckweeds and pond-lilies, have them floating; and still others, like the sedges, the bur reeds (Plate XII), and the cat-tails (Plate VII), have their leaves freely exposed to the air. A few plants have both water leaves and air leaves (Fig. 79). It is generally supposed that the thread-like form of submerged leaves in so many species of aquatics gives them greater capacity to absorb dissolved gases from the water which surrounds them.

FIG. 79. Submerged and Aërial Leaves of a European Crowfoot (*Ranunculus Purshii*). The leaf with thread-like divisions is the submerged one.

136. Leaves of Xerophytes.—In regions where the greatest dangers to vegetation arise from long droughts and the excessive heat of the sun, the leaves of plants usually offer much less surface to the sun and air than is the case in temperate climates, as shown in the Australian blackberry (Fig. 80). Sometimes the blade of the leaf is absent and the expanded petiole answers the purpose of a blade, or, again, foliage leaves are altogether lacking, as in

the cactuses (Fig. 81), and the green outer layers of the stem do the work of the leaves.

137. Rolled-Up Leaves. — Leaves which receive but a scanty supply of water are often protected from losing it

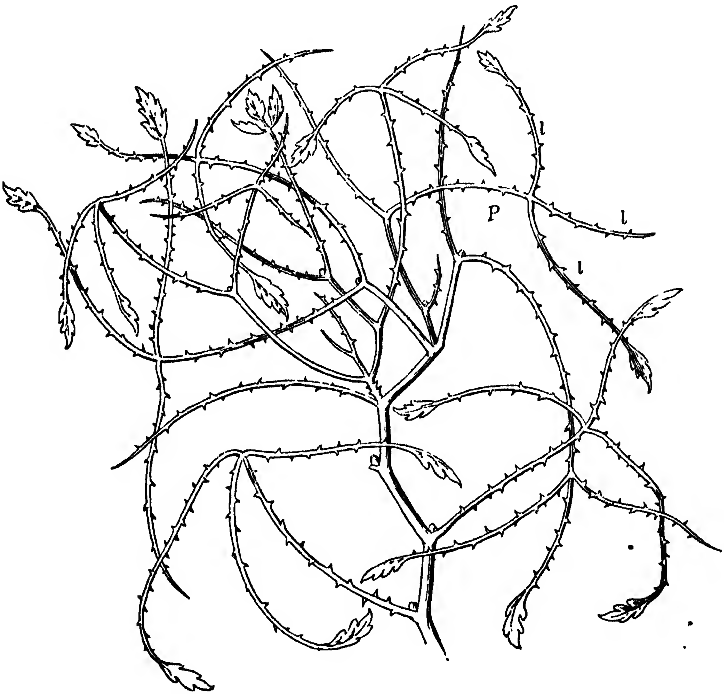


FIG. 80. Xerophytic Leaves of Australian Blackberry.

l, leaflets reduced in many cases to bare midribs, in other cases showing a bit of blade at the end; *P*, petiole.

too rapidly by being rolled up, so that the evaporating, *i.e.*, stomata-containing, surface is on the inside of the roll. Sometimes, as in the crow-berry (Fig. 82), the curled

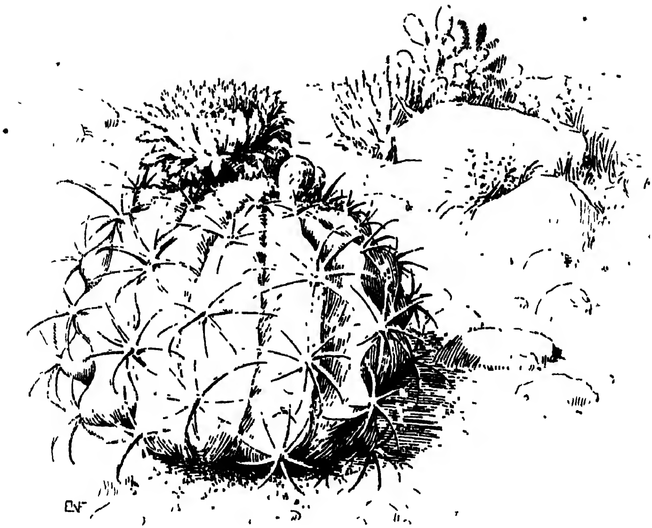


Fig 81. Melon-Cactus.

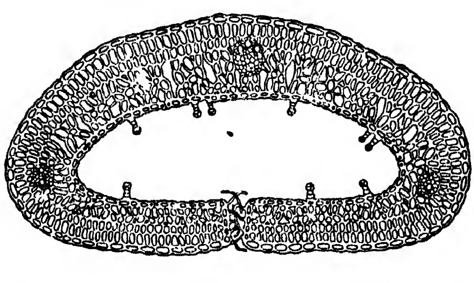


Fig. 82. Cross-Section of Rolled-Up Leaf of Crow-Berry (*Empetrum nigrum*). (Magnified.)

condition is permanent. In other plants, as in Indian corn, the leaf rolls up when the weather is very dry and unrolls again when it receives a better supply of water.

138. Fleshy Leaves. — Many xerophytes and a still larger proportion of halophytes have thick, fleshy leaves, sometimes thick at the base and tapering to a point often nearly cylindrical in form. The common portulaca, the so-called "ice-plants," and the century-plant offer familiar examples of fleshy leaves. Leaves of this form stand exposure to the hottest sunshine, even when the plant is scantily supplied with water.

FIG. 83. Common Pitcher-Plant (*Sarracenia purpurea*).

At the right one of the pitcher-like leaves is shown in cross-section.

139. Leaves of Mesophytes. — The great majority of foliage leaves, such as those of most common garden herbs, grasses, clovers, and so on, belong to this class. They are neither remarkably thick nor thin, expanded nor scanty in surface, and they show no such special adaptations as rolling up to avoid the parching effect of excessive sunshine.

Plate VIII. Prickly Pear Cactus.

FIG. 84. Sundew (*Drosera rotundifolia*).

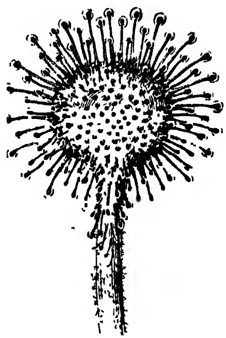


FIG. 85. Blade of Leaf of Sundew. (Somewhat magnified.)

140. Carnivorous Plants. — In the ordinary pitcher-plants (Fig. 83) the leaf appears in the shape of a more or less hooded pitcher. These pitchers are usually partly filled with water, and in this water very many drowned and decaying insects are commonly to be found. The insects have flown or crawled into the pitcher, and, once inside, have been unable to escape on account of the dense growth of bristly hairs about the mouth, all pointing inward and downward. How much the common American pitcher-plants depend for nourishment on the drowned insects in the pitchers is not definitely known, but it is certain that some of the tropical species require such food.[1]

FIG. 86. Leaves of Sundew. (Somewhat magnified.)

The one at the left has all its tentacles closed over captured prey; the one at the right has only half of them thus closed.

In other rather common plants, the sundews, insects are caught by a sticky secretion which proceeds from hairs on the leaves. In one of the commonest sundews the leaves consist of a roundish blade borne on a moderately long

[1] Where the *Sarracenia* is abundant it will be found interesting and profitable to make a careful class study of its leaves. See Geddes' *Chapters in Modern Botany*, Chapters I and II.

petiole. On the inner surface and round the margin of the blade (Fig. 85) are borne a considerable number of short bristles, each terminating in a knob which is covered with a clear, sticky liquid. When a small insect touches one of the sticky knobs, he is held fast and the hairs at once begin to close over him, as shown in Fig. 86. Here he soon dies and then usually remains for many days, while the leaf pours out a juice by which the soluble parts of the insect are digested. The liquid containing the digested portions is then absorbed by the leaf and contributes an important part of the nourishment of the plant, while the undigested fragments, such as legs, wing-cases, and so on, remain on the surface of the leaf or may drop off after the hairs let go their hold on the captive insect.

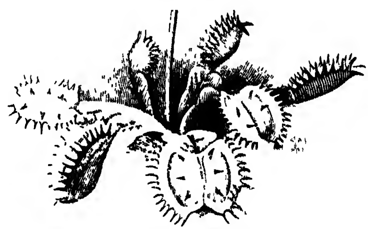


FIG. 87. Venus' Flytrap.

In the Venus' flytrap, which grows in the sandy regions of eastern North Carolina, the mechanism for catching insects is still more remarkable. The leaves, as shown in Fig. 87, terminate in a hinged portion which is surrounded by a fringe of stiff bristles. On the inside of each half of the trap grow three short hairs. The trap is so sensitive that when these hairs are touched it closes rather rapidly

and very generally succeeds in capturing the fly or other insect which has sprung it. The imprisoned insect then dies and is digested, somewhat as in the case of those caught by the sundew, after which the trap reopens and is ready for fresh captures.

141. Object of catching Animal Food. — It is easy to understand why a good many kinds of plants have taken to catching insects and absorbing the digested products. Carnivorous, or flesh-eating, plants belong usually to one of two classes as regards their place of growth: they are bog-plants or air-plants. In either case their roots find it difficult to secure much nitrogen-containing food, — that is, much food out of which proteid material can be built up. Animal food, being itself largely proteid, is admirably adapted to nourish the growing parts of plants, and those which could develop insect-catching powers would stand a far better chance to exist as air-plants or in the thin, watery soil of bogs than plants which had acquired no such resources.

142. Destruction of Plants by Animals. — All animals are supported directly or indirectly by plants. In some cases the animal secures its food without much damage to the plant on which it feeds. Browsing on the lower branches of a tree may do it little injury, and grazing animals, if not numerous, may not seriously harm the pasture on which they feed. Fruit-eating animals may even be of much service by dispersing seeds. But seed eating birds and quadrupeds, animals which, like the hog, dig up fleshy roots, rootstocks, tubers, or bulbs, and eat them, or animals which, like the sheep, graze so closely as to expose the roots of grasses or even of forest trees to be parched by the sun, destroy immense numbers of plants

So too with leaf-eating insects and snails, which consume great quantities of leaves.

143. Plants of Uneatable Texture. — Whenever tender and juicy herbage is to be had, plants of hard and stringy texture are left untouched. In pastures there grow such perennials as the bracken fern and the hardhack of New England and the ironweed and vervains of the Central States, which are so harsh and woody that the hungriest browsing animal is rarely, if ever, seen to molest them. Still other plants, like the knot-grass and cinquefoil of our dooryards,

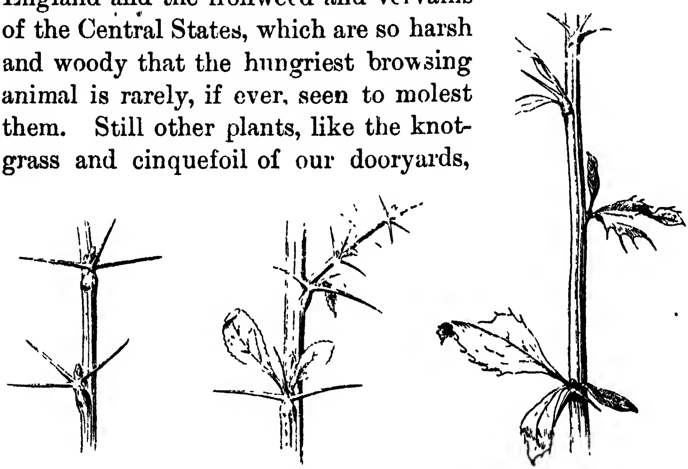


Fig. 88. Spiny Leaves of Barberry.

are doubly safe from their growing so close to the ground as to be hard to graze and from their woody and unpalatable nature. The date-palm (which can easily be raised from the seed in the schoolroom or the laboratory) is an excellent instance of the same uneatable quality found in a tropical or subtropical plant.

144. Plants with Weapons for Defense.[1] — Multitudes of plants, which might otherwise have been subject to the

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. I, p. 430.

attacks of grazing or browsing animals, have acquired what have with reason been called weapons. Among the most conspicuous of these are thorns, which are often modified branches. Thorns, which are really modified leaves, are very perfectly exemplified in the barberry (Fig. 88). It is much commoner to find the leaf extending its midrib or its veins out into spiny points, as the thistle does, or bearing spines or prickles on its midrib, as is the case with the nightshade shown in Fig. 89, and with so many roses.

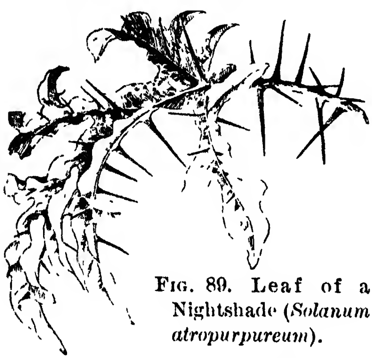


FIG. 89. Leaf of a Nightshade (*Solanum atropurpureum*).

Stipules are not infrequently found occurring as thorns, and in our common locust (Fig. 91) the bud, or the very young shoot which proceeds from it, is admirably protected by the jutting thorn on either side.

145. Pointed, Barbed, and Stinging Hairs. — Needle-pointed hairs are an efficient defensive weapon of many plants. Sometimes these hairs are roughened, like those of the bugloss (Fig. 92, *b*); sometimes they are decidedly barbed. If the barbs are well developed, they may cause the hairs to travel far into the flesh of animals and cause intense pain. In the nettle (Fig. 92, *a*) the hairs are efficient stings, with a brittle tip, which on breaking off exposes a sharp, jagged tube full of irritating fluid. These tubular hairs, with their poisonous contents, will be found sticking in the skin of the hand or the face after incautious contact with nettles, and the violent itching which follows is only too familiar to most people.

146. Cutting Leaves. — Some grasses and sedges are generally avoided by cattle because of the sharp cutting edges of their leaves, which will readily slit the skin of one's hand if they are drawn rapidly through the fingers. Under the microscope the margins of

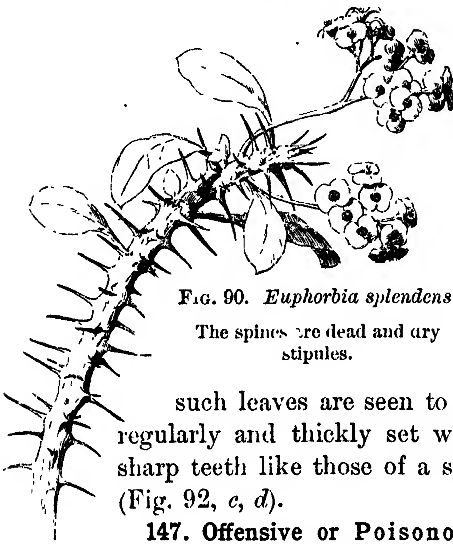


FIG. 90. *Euphorbia splendens.* The spines are dead and dry stipules.

such leaves are seen to be regularly and thickly set with sharp teeth like those of a saw (Fig. 92, *c*, *d*).

147. Offensive or Poisonous Plants. — A disgusting smell is one of the common safeguards which keep plants from being eaten. The dog-fennel, the hound's-tongue (*Cynoglossum*), the Martynia, and the tomato-plant are common examples of rank-smelling plants which are offensive to most grazing animals and so are let alone by them. Oftentimes, as in the case of the jimson weed (*Datura*), the tobacco-plant, and the poison hemlock (*Conium*), the smell serves as a warning of the poisonous nature of the plant. A bitter, nauseating, or biting taste protects many plants from destruction by animals.

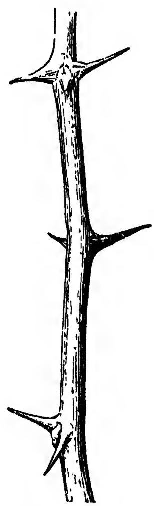


FIG. 91. Thorn Stipules of Locust.

Buckeye, horse-chestnut, and maple twigs and leaves are so bitter that browsing animals and most insects let them alone. Tansy, ragweed, boneset, southernwood, and wormwood are safe for the same reason. The nauseous taste of

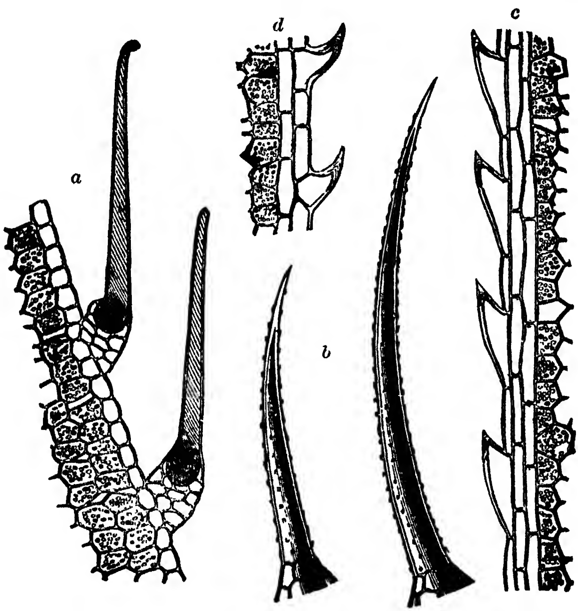


FIG. 92. Stinging Hairs and Cutting Leaves. (All much magnified.)

a, stinging hairs on leaf of nettle; *b*, bristle of the bugloss; *c*, barbed margin of a leaf of sedge; *d*, barbed margin of a leaf of grass.

many kinds of leaves and stems, such as those of the potato, and the fiery taste of horse-radish, make these substances uneatable for most animals.

Poisonous plants are usually shunned by grown-up animals, though the young ones will sometimes eat such plants and may be killed by them.

CHAPTER XIII

MINUTE STRUCTURE OF LEAVES; FUNCTIONS OF LEAVES

148. Leaf of Lily. — A good kind of leaf with which to begin the study of the microscopical structure of leaves in general is that of the lily.[1]

149. Cross-Section of Lily Leaf. — The student should first examine with the microscope a cross-section of the leaf, that is, a very thin slice, taken at right angles to the upper and under surfaces and to the veins. This will show:

(*a*) The upper epidermis of the leaf, a thin, nearly transparent membrane.

(*b*) The intermediate tissues.

(*c*) The lower epidermis.

Use a power of from 100 to 200 diameters. In order to ascertain the relations of the parts and to get their names, consult Fig. 93. Your section is by no means exactly like the figure; sketch it. Label properly all the parts shown in your sketch.

Are any differences noticeable between the upper and the lower epidermis? between the layers of cells immediately adjacent to each?

150. Under Surface of Lily Leaf. — Examine with a power of 200 or more diameters the outer surface of a piece of epidermis from the lower side of the leaf.[2] Sketch carefully, comparing your sketch with Fig. 94, *B*, and labeling it to agree with that figure.

[1] Any kind of lily will answer.

[2] The epidermis may be started with a sharp knife, then peeled off with small forceps, and mounted in water for microscopical examination.

151. Stomata. — A *stoma* is a microscopic pore or slit in the epidermis. It is bounded and opened and shut by guard-cells (Fig. 94, *g*), usually two in number. These

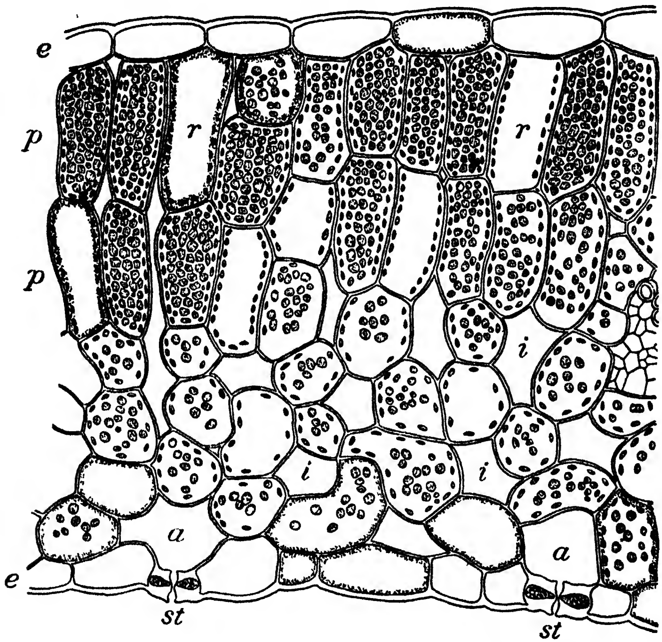


FIG. 93. Vertical Section of the Leaf of the Beet. (Much magnified.)
e, epidermis; *p*, palisade-cells (and similar elongated cells); *r*, cells filled with red cell-sap; *i*, intercellular spaces; *a*, air spaces communicating with the stomata; *st*, stomata, or breathing pores.

are generally somewhat kidney-shaped and become more or less curved as they are fuller or less full of water (see Sect. 158).

In the case of an apple tree, where the epidermis of the lower surface of the leaf contains about 24,000 stomata to

the square inch, or the black walnut, with nearly 300,000 to the square inch, the total number on a tree is inconceivably large.

152. Uses of the Parts examined. — It will be most convenient to discuss the uses of the parts of the leaf a little later, but it will make matters simpler to state at once that the epidermis serves as a mechanical protection to the parts beneath and prevents excessive evaporation, that the palisade-cells (which may not be made out very clearly in a roughly prepared section) hold large quantities of the green coloring matter of the leaf in a position where it can receive enough but not too much sunlight, and that the cells of the spongy parenchyma share the work of the palisade-cells, besides evaporating much water. The stomata admit air to the interior of the leaf (where the air spaces serve to store and to distribute it), they allow oxygen and carbonic

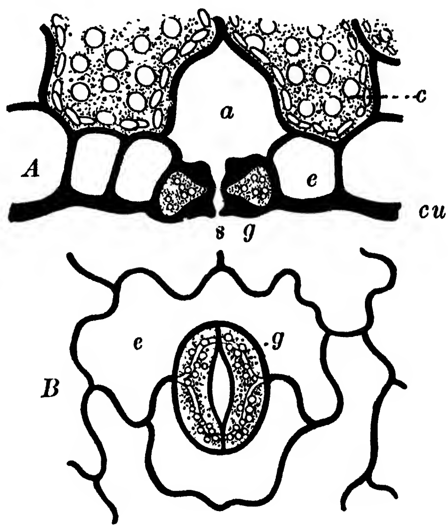


FIG. 94. A Stoma of Thyme. (Greatly magnified.)

A, section at right angles to surface of leaf; *B*, surface view of stoma. *cu*, cuticle; *g*, guard-cells; *s*, stoma; *e*, epidermal cells; *a*, air chamber; *c*, cells of spongy parenchyma with grains of chlorophyll.

acid gas to escape, and, above all, they regulate the evaporation of water from the plant.

153. Chlorophyll as found in the Leaf. — Slice off a little of the epidermis from some such soft, pulpy leaf as that of the common field sorrel,[1] live-for-ever, or spinach; scrape from the exposed portion a very little of the green pulp; examine with the highest power attainable with your microscope, and sketch several cells. Also study the chlorophyll in a small moss leaf, *e.g.*, of *Mnium*.

Notice that the green coloring matter is not uniformly distributed, but that it is collected into little particles called *chlorophyll bodies* (Figs. 93, 94).

154. Woody Tissue in Leaves. — The veins of leaves consist of fibro-vascular bundles containing wood and vessels much like those of the stem of the plant. Indeed, these bundles in the leaf are continuous with those of the stem, and consist merely of portions of the latter, looking as if unraveled, which pass outward and upward from the stem into the leaf under the name of *leaf-traces*. These traverse the petiole often in a somewhat irregular fashion. It is now easy to see that the dots noted on the leaf-scars of the horse-chestnut, the *Ailanthus* (Fig. 49), and other trees, are merely the spots at which the leaf-traces passed from stem to petiole.

155. Experimental Study of Functions of Leaves. — The most interesting and profitable way in which to find out what work leaves do for the plant is by experimenting upon them. Much that relates to the uses of leaves is not readily shown in ordinary class-room experiments, but some things can readily be demonstrated in the experiments which follow.

[1] *Rumex Acetosella.*

EXPERIMENT XIV

Transpiration. — Take two twigs or leafy shoots of any thin-leaved plant;[1] cover the cut end of each stem with a bit of grafting wax[2] to prevent evaporation from the cut surface. Put one shoot into a fruit jar and leave in a warm room, screw the top on, put the other beside it, and allow both to remain some hours. Examine the relative appearance of the two, as regards wilting, at the end of the time.

Which shoot has lost most? Why? Has the one in the fruit jar lost any water? To answer this question put the jar (without opening it) into a refrigerator, or, if the weather is cold, out of doors for a few minutes, and examine the appearance of the inside of the jar. What does this show?[3]

156. Uses of the Epidermis.[4] — The epidermis, by its toughness, tends to prevent mechanical injuries to the leaf, while by the transformation of a portion of its outer layers into a corky substance it greatly diminishes the loss of water from the general surface. In most cases, as in the india-rubber tree, the epidermal cells (and often two or three layers of cells beneath these) are filled with water, and thus serve as reservoirs from which the outer parts of the leaf and the stem are at times supplied.

In many cases, noticeably in the cabbage, the epidermis is covered with a waxy coating which doubtless increases the power of the leaf to retain needed moisture, and which certainly prevents rain or dew from covering the leaf-surfaces, especially the lower surfaces, so as to prevent the operation of the stomata. Many common plants, like

[1] Hydrangea, squash, melon, or cucumber is best; many other kinds will answer very well.

[2] Grafting wax may be bought of nurserymen or seedsmen.

[3] If the student is in doubt whether the jar filled with ordinary air might not behave in the same way, the question may be readily answered by putting a sealed jar of air into the refrigerator.

[4] See Kerner and Oliver's *Natural History of Plants*, Vol. I, pp. 273–362.

the meadow rue and the nasturtium, possess this power to shed water to such a degree that the under surface of the leaf is hardly wet at all when immersed in water, and the air-bubbles on the leaves give them a silvery appearance when held under water.

157. Hairs on Leaves. — Many kinds of leaves are more or less hairy or downy, as those of the mullein, the "mullein pink," many cinquefoils, and other common plants. In some instances this hairiness may be a protection against snails or other small leaf-eating animals, but in other cases it seems to be pretty clear that the woolliness (so often confined to the under surface) is to lessen the loss of water through the stomata.

158. Operation of the Stomata. — The stomata serve to admit air to the interior of the leaf and to allow moisture, in the form of vapor, to pass out of it. They do this not in a passive way, as so many mere holes in the epidermis might, but to some extent they regulate the rapidity of transpiration, opening more widely in damp weather and closing in dry weather. The opening is produced by each of the guard-cells bending into a more kidney-like form than usual, and the closing by a straightening out of the guard-cells. The under side of the leaf, free from palisade-cells and abounding in intercellular spaces, is especially adapted for the working of the stomata, and accordingly we find them in much greater numbers on the lower than on the upper surface. On the other hand, the little flowerless plants known as liverworts, which lie prostrate on the ground, have their stomata on the upper surface, and so do the leaves of pond-lilies, which lie flat on the water. In those leaves which stand with their edges nearly vertical, the stomata are distributed somewhat equally on both

surfaces. Stomata occur on the epidermis of young stems, being replaced later by the lenticels. Those plants which, like the cactuses, have no ordinary leaves, transpire through the stomata scattered over their general surfaces.

EXPERIMENT XV

Amount of Water lost by Transpiration. — Procure a thrifty hydrangea[1] growing in a small flower-pot. Calculate the area of the leaf-surface by dividing the surface of a piece of tracing cloth into a series of squares one-half inch on a side, holding an average leaf against this, and counting the number of squares and parts of squares covered by the leaf. This area multiplied by the number of leaves will give approximately the total evaporating surface.

Transfer the plant to a glass battery jar of suitable size. Cover the jar with a piece of sheet lead, slit to admit the stem of the plant, invert the jar, and seal the lead to the glass with a hot mixture of beeswax and resin. Seal up the slit and the opening about the stem with grafting wax. A thistle-tube, such as is used by chemists, is also to be inserted, as shown in Fig. 95.[2] The mouth of this should be kept corked when the tube is not in use for watering.

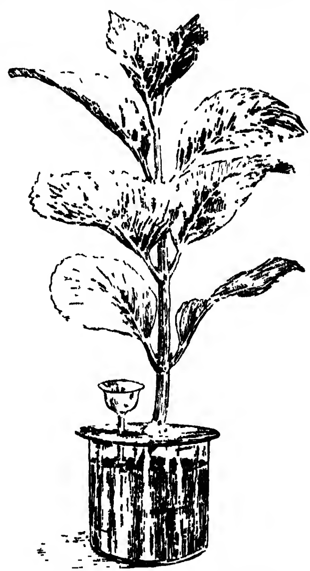


FIG. 95. A Hydrangea for Exp. XV.

[1] The common species of the greenhouses, *Hydrangea Hortensia*.

[2] It will be much more convenient to tie the hydrangea if one has been chosen that has but a single main stem. Instead of the hydrangea the common cineraria, *Senecio cruentus*, does very well.

Water moderately and weigh on a balance that is sensitive to one or two grams. Record the weight, allow the plant to stand in a sunny, warm room for twenty-four hours, and reweigh.

Add just the amount of water which is lost,[1] and continue the experiment in the same manner for several days so as to ascertain, if possible, the effect upon transpiration of varying amounts of water in the atmosphere.

Calculate the loss per 100 square inches of leaf-surface throughout the whole course of the experiment.

Try the effect of supplying very little water, so that the hydrangea will begin to droop, and see whether this changes the relative amount of transpiration. Vary the conditions of the experiment for a day or two as regards temperature, and again for a day or two as regards light, and note the effect upon the amount of transpiration.[2]

EXPERIMENT XVI

Rise of Sap in Leaves. — Put the freshly cut ends of the petioles of several thin leaves of different kinds into small glasses, each containing red ink to the depth of one-quarter inch or more. Allow them to stand for half an hour, and examine by holding up to the light and looking through them to see into what parts the red ink has risen. Allow some of the leaves to remain as much as twelve hours and examine them again. The red-stained portions of the leaf mark the lines along which, under natural conditions, sap rises into it. Cut across (near the petiole or midrib ends) all the principal veins of some kind of large, thin leaf. Then cut off the petiole and at once stand the cut end, to which the blade is attached, in red ink. Repeat with another leaf and stand in water. What do the results teach?

159. Amount of Transpiration. — In order to prevent wilting, the rise of sap during the life of the leaf must

[1] The addition of known amounts of water may be made most conveniently by measuring it in a cylindrical graduate.

[2] When the experiments on the hydrangea have been finished, it should be kept moderately watered and left sealed up until it is needed for a later experiment.

have kept pace with the evaporation from its surface. A little calculation will show that the amount of water thus daily carried off through the foliage of a large tree or the grass-blades on a meadow is enormous. A grass-plant has been found to give off its own weight of water every twenty-four hours, in hot, dry summer weather. This would make about 6½ tons per acre every twenty-four hours for ordinary grass-fields, or rather over 2200 pounds of water from a field 50 × 150 feet (*i.e.*, a city lot).

These large amounts of water are absorbed, carried through the tissues of the plant, and then given off by the leaves simply because the plant-food contained in the soil-water is in a condition so diluted that great quantities of water must be taken in order to secure enough of the mineral and other substances which the plant demands from the soil.

160. Accumulation of Mineral Matter in the Leaf.—Just as a deposit of salt is found in the bottom of a seaside pool of salt water which has been dried up by the sun, so old leaves are found to be loaded with mineral matter left behind as the sap drawn up from the roots is evaporated through the stomata. A bonfire of leaves makes a surprisingly large heap of ashes. An abundant constituent of the ashes of burnt leaves is *silica*, a substance chemically the same as sand. This the plant is forced to absorb along with the potash, compounds of phosphorus, and other useful substances contained in the soil-water; but since the silica is of hardly any value to most plants, it often accumulates in the leaf as so much refuse. Lime is much more useful to the plant than silica, but a far larger quantity of it is absorbed than is needed; hence it, too, accumulates in the leaf.

161. Details of the Work of the Leaf.[1] — A leaf has four important functions to perform:

(1) Fixation of carbon, or starch-making.
(2) Assimilation.[2]
(3) Excretion of water.
(4) Respiration.

162. Absorption of Carbon Dioxide and Removal of its Carbon. — Carbon dioxide is a constant ingredient of the atmosphere, usually occurring in the proportion of about four parts in every 10,000 of air, or one twenty-fifth of one per cent. It is a colorless gas, a compound of two simple substances or elements, carbon and oxygen, the former familiar to us in the forms of charcoal and graphite, the latter occurring as the active constituent of air.

Carbon dioxide is produced in immense quantities by the decay of vegetable and animal matter, by the respiration of animals, and by all fires in which wood, coal, gas, or petroleum is burned.

Green leaves and the green parts of plants, when they contain a suitable amount of potassium salts, have the power of removing carbon dioxide from the air (or in the case of some aquatic plants from water in which it is dissolved), retaining its carbon, and setting free part or all of the oxygen. This process is an important part of the work done by the plant in making over raw materials into food from which it forms its own substance.

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. I, pp. 371–483.
[2] In many works on botany (1) and (2) are both compounded under the term *assimilation*.

EXPERIMENT XVII

Oxygen-Making in Sunlight. — Place a green aquatic plant in a glass jar full of ice-cold fresh water, in front of a sunny window.[1] Place a thermometer in the jar, watch the rise of temperature, and note at what point you first observe the formation of oxygen bubbles. Remove to a dark closet for a few minutes and examine by lamplight to see whether the rise of bubbles still continues.

This gas may be shown to be oxygen by collecting some of it in a small inverted test-tube filled with water and thrusting the glowing coal of a match just blown out into the gas. It is not, however, very easy to do this satisfactorily before the class.

Repeat the experiment, using water which has been well boiled and then quickly cooled. Boiling removes all the dissolved gases from water, and they are not redissolved in any considerable quantity for many hours.

Ordinary air containing a known per cent of carbon dioxide, if passed very slowly over the foliage of a plant covered with a bell-glass and placed in full sunlight, will, if tested chemically, on coming out of the bell-glass, be found to have lost a little of its carbon dioxide. The pot in which the plant grows must be covered with a lid, closely sealed on, to prevent air charged with carbon dioxide (as the air of the soil is apt to be) from rising into the bell-glass.

163. Disposition made of the Absorbed Carbon Dioxide. — It would lead the student too far into the chemistry of botany to ask him to follow out in detail the changes by which carbon dioxide lets go at least part of its oxygen and gives its remaining portions, namely the carbon and perhaps part of its oxygen, to build up the substance of

[1] *Elodea, Myriophyllum, Chrysosplenium, Potamogeton, Fontinalis,* any of the green aquatic flowering plants, or even the common confervaceous plants, known as *pond-scum* or "frog-spit," will do for this experiment.

the plant. Starch is composed of three elements: hydrogen (a colorless, inflammable gas, the lightest of known substances), carbon, and oxygen. Water is composed largely of hydrogen, and therefore carbon dioxide and water contain all the elements necessary for making starch. The chemist cannot put these elements together to form starch, but the plant can do it, and at suitable temperatures starch-making goes on constantly in the green parts of plants when exposed to sunlight and supplied with water and carbon dioxide.[1] The seat of the manufacture is in the chlorophyll bodies, and protoplasm is without doubt the manufacturer, but the process is not understood by chemists or botanists. No carbon dioxide can be taken up and used by plants growing in the dark, nor in an atmosphere containing only carbon dioxide, even in the light.

A very good comparison of the leaf to a mill has been made as follows[2]:

The mill:	Palisade-cells and underlying cells of the leaf.
Raw material used:	Carbon dioxide, water.
Milling apparatus:	Chlorophyll grains.
Energy by which the mill is run:	Sunlight.
Manufactured product:	Starch.
Waste product:	Oxygen.

164. Plants Destitute of Chlorophyll not Starch-Makers. — Aside from the fact that newly formed starch grains are first found in the chlorophyll bodies of the leaf and

[1] Very likely the plant makes sugar first of all and then rapidly changes this into starch. However that may be, the first kind of food made in the leaf and retained long enough to be found there by ordinary tests is starch. See Pfeffer's *Physiology of Plants*, translated by Ewart, Vol. I, pp. 317, 318.

[2] By Professor George L. Goodale.

PLATE IX. A Saprophyte, Indian Pipe.

the green layer of the bark, one of the best evidences of the intimate relation of chlorophyll to starch-making is derived from the fact that plants which contain no chlorophyll cannot make starch from water and carbon dioxide. Parasites, like the dodder, which are nearly destitute of green coloring matter, cannot do this; neither can *saprophytes* or plants which live on decaying or fermenting organic matter, animal or vegetable. Most saprophytes, like the molds, toadstools, and yeast, are flowerless plants of low organization, but there are a few (such as the Indian pipe (Plate IX), which flourishes on rotten wood or among decaying leaves) that bear flowers and seeds.

165. Detection of Starch in Leaves. — Starch may be found in abundance by microscopical examination of the green parts of growing leaves, or its presence may be shown by testing the whole leaf with iodine solution.

EXPERIMENT XVIII

Occurrence of Starch in Nasturtium Leaves. — Toward the close of a very sunny day collect some bean leaves or leaves of nasturtium (*Tropæolum*). Boil these in water for a few minutes to kill the protoplasmic contents of the cells and to soften and swell the starch grains.

Soak the leaves, after boiling, in strong alcohol for a day or two to dissolve out the chlorophyll, which would otherwise make it difficult to see the blue color of the starch test, if any were obtained. Rinse out the alcohol with plenty of water and then place the leaves for ten or fifteen minutes in a solution of iodine, rinse off with water, and note what portions of the leaf, if any, show the presence of starch.

If convenient try the test with a leaf treated as shown in Fig. 96.

What might this prove about importance of sunlight?

If starch disappeared from between the corks, where did it go?

Review Sects. 17–21, 95–97. Read Sect. 166.

166. Assimilation. — From the starch in the leaf, grape-sugar or malt-sugar is readily formed, and some of this in turn is apparently combined on the spot with nitrogen, sulphur, and phosphorus. These elements are derived from nitrates, sulphates, and phosphates taken up in a dissolved condition by the roots of the plant and transported to the leaves. The details of the process are not understood, but the result of the combination of the sugars or similar substances with suitable (very minute) proportions of nitrogen, sulphur, and phosphorus is to form complex nitrogen compounds. These are not precisely of the same composition as the living protoplasm of plant-cells or as the reserve proteids stored in seeds (Sect. 24), stems (Sect. 91), and other parts of plants, but are readily changed into protoplasm or proteid foods as necessity may demand.

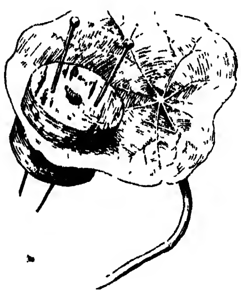


Fig. 96. Leaf of Tropæolum partly covered with Disks of Cork and exposed to Sunlight.

Assimilation is by no means confined to leaves; indeed, most of it, as above suggested, must take place in other parts of the plant.

167. Excretion of Water and Respiration. — Enough has been said in Sect. 159 concerning the former of these processes. *Respiration*, or breathing in oxygen and giving off carbonic acid gas, is an operation which goes on constantly in plants, as it does in animals, and is necessary to their life. For, like animals, plants get the energy with which they do the work of assimilation, growth, reproduction, and performing their movements from the oxidation

of such combustible substances as oil, starch, and sugar.[1] In ordinary leafy plants the leaves (through their stomata) are the principal organs for absorption of air, but much air passes into the plant through the lenticels of the bark.

168. The Fall of the Leaf. — In the tropics trees retain most of their leaves the year round; a leaf occasionally falls, but no considerable portion of them drops at any one season.[2] The same statement holds true in regard to our cone-bearing evergreen trees, such as pines, spruces, and the like. But the impossibility of absorbing soil-water when the ground is at or near the freezing temperature would cause the death, by drying up, of trees with broad leaf-surfaces in a northern winter. And in countries where there is much snowfall most broad-leafed trees could not escape injury to their branches from overloading with snow, except by encountering winter storms in as close-reefed a condition as possible. For such reasons our common shrubs and forest trees (except the cone-bearing, narrow-leafed ones already mentioned) are mostly *deciduous*, that is, they shed their leaves at the approach of winter.

The fall of the leaf is preceded by important changes in the contents of its cells.

Much of the starchy, sugary, and protoplasmic contents of the leaf disappears before it falls. These valuable materials have been absorbed by the branches and roots, to be used again the following spring.

The separation of the leaf from the twig is accomplished by the formation of a layer of cork cells across the base of

[1] The necessity of an air supply about the roots of the plant may be shown by filling the pot or jar in which the hydrangea was grown for the transpiration experiment perfectly full of water and noting the subsequent appearance of the plant at periods from twelve to twenty-four hours apart.

[2] Except where there is a severe dry season.

the petiole in such a way that the latter finally breaks off across the surface of the layer. A waterproof scar is thus already formed before the removal of the leaf, and there is no waste of sap dripping from the wound where the leaf-stalk has been removed, and no chance for molds to attack the bark or wood and cause it to decay.

169. Tabular Review of Experiments. — [Continue the table from Sect. 102.]

170. Review Summary of Minute Structure of Leaves.[1]

Layers of tissue seen on a cross-section . . . .
Structure of epidermis.
Structure of stomata.
Distribution of stomata.
Structure and distribution of chlorophyll bodies.

171. Review Summary of Functions of Leaves.

Principal uses of	fibro-vascular bundles. epidermis. stomata. air spaces. palisade-cells. spongy parenchyma. waxy coating. hairs.
Substances received by the leaf	from the air. from the soil.
Substances manufactured by the leaf.	
Substances given off by the leaf	into the air. into the stem.
Mineral substances accumulated in the leaf.	
Statistics in regard to transpiration.	

[1] Illustrate with sketches and diagrams.

CHAPTER XIV

THE STUDY OF TYPICAL FLOWERS

172. The Flower of the Trillium. — Cut off the flower-stalk rather close to the flower; stand the latter, face down, on the table and draw the parts then shown. Label the green leaf-like parts *sepals*, and the white parts, which alternate with these, *petals*. Turn the flower face up, and make another sketch, labeling the parts as before, together with the yellow enlarged extremities or *anthers* of the stalked organs called *stamens*.

Note and describe the way in which the petals alternate with the sepals. Observe the arrangement of the edges of the petals toward the base, — how many with both edges outside the others, how many with both edges inside, how many with one edge in and one out.

Note the veining of both sepals and petals, — more distinct in which set?[1]

Pull off a sepal and make a sketch of it, natural size; then remove a petal, flatten it out, and sketch it, natural size.

Observe that the flower-stalk is enlarged slightly at the upper end into a rounded portion, the *receptacle*, on which all the parts of the flower rest.

Note how the six stamens arise from the receptacle and their relations to the origins of the petals. Remove the remaining petals (cutting them off near the bottom with a knife), and sketch the stamens, together with the other object, the *pistil*, which stands in the center.

[1] In flowers with delicate white petals the distribution of the fibro-vascular bundles in these can usually be readily shown by standing the freshly cut end of the peduncle in red ink for a short time, until colored veins begin to appear in the petals. The experiment succeeds readily with apple, cherry, or plum blossoms; with white gilliflower the coloration is very prompt. Lily-of-the-valley is perhaps as interesting a flower as any on which to try the experiment, since the well-defined stained stripes are separated by portions quite free from stain, and the pistils are also colored.

Cut off one stamen, and sketch it as seen through the magnifying glass. Notice that it consists of a greenish stalk, the *filament*, and a broader portion, the *anther* (Fig. 108). The latter is easily seen to contain a prolongation of the green filament, nearly surrounded by a yellow substance. In the bud it will be found that the anther consists of two long pouches or *anther-cells*, which are attached by their whole length to the filament and face inward (towards the center of the flower). When the flower is fairly open the anther-cells have already split down their margins and are discharging a yellow, somewhat sticky powder, the *pollen*.

Examine one of the anthers with the microscope, using the two-inch objective, and sketch it.

Cut away all the stamens and sketch the *pistil*. It consists of a stout lower portion, the *ovary*, which is six-ridged or angled, and which bears at its summit three slender *stigmas*.

In another flower, which has begun to wither (and in which the ovary is larger than in a newly opened flower), cut the ovary across about the middle, and try to make out with the magnifying glass the number of chambers or *cells* which it contains. Examine the cross-section with the two-inch objective, sketch it, and note particularly the appearance and mode of attachment of the undeveloped seeds or *ovules* with which it is filled. Make a vertical section of another rather mature ovary, and examine this in the same way.

Using a fresh flower, construct a diagram to show the relation of the parts on an imaginary cross-section, as illustrated in Fig. 116.[1] Construct a diagram of a longitudinal section of the flower, on the general plan of those in Fig. 114, but showing the contents of the ovary.

Make a tabular list of the parts of the flower, beginning with the sepals, giving the order of parts and number in each set.

173. The Flower of the Tulip.[2] — Make a diagram of a side view of the well-opened flower as it appears when standing in sunlight.

[1] It is important to notice that such a diagram is not a picture of the section actually produced by cutting through the flower crosswise at any one level, but that it is rather a *projection* of the sections through the most typical part of each of the floral organs.

[2] *Tulipa gesneriana.* As the flowers are rather expensive and their parts are large and firm, it is not absolutely necessary to give a flower to each pupil, but some may be kept entire for sketching and others dissected by the class. All the flowers must be single.

Observe that there is a set of outer flower-leaves and a set of inner ones.[1] Label the outer set *sepals* and the inner set *petals*. In most flowers the parts of the outer set are greenish, and those of the inner set of some other color. It is often convenient to use the name *perianth*, meaning around the flower, for the two sets taken together. Note the white waxy bloom on the outer surface of the outer segments of the perianth. What is the use of this? Note the manner in which the inner segments of the perianth arise from the top of the peduncle and their relation to the points of attachment of the outer segments. In a flower not too widely opened, note the relative position of the inner segments of the perianth, — how many wholly outside the other two, how many wholly inside, how many with one edge in and one edge out.

Remove one of the sepals by cutting it off close to its attachment to the peduncle, and examine the veining by holding it up in a strong light and looking through it. Make a sketch to show the general outline and the shape of the tip.

Examine a petal in the same way and sketch it.

Cut off the remaining portions of the perianth, leaving about a quarter of an inch at the base of each segment. Sketch the upright, triangular, pillar-like object in the center and label it *pistil;* sketch the organs which spring from around its base and label these *stamens*.

Note the fact that each stamen arises from a point just above and within the base of a segment of the perianth. Each stamen consists of a somewhat conical or awl-shaped portion below, the *filament*, surmounted by an ovate linear portion, the *anther*. Sketch one of the stamens about twice natural size and label it × 2. Is the attachment of the anther to the filament such as to admit of any nodding or twisting movement of the former? In a young flower, note the two tubular pouches or anther-cells of which the anther is composed, and the slits by which these open. Observe the dark-colored *pollen* which escapes from the anther-cells and adheres to paper or to the fingers. Examine a newly opened anther with the microscope, using the two-inch objective, and sketch it.

Cut away all the stamens and note the two portions of the pistil, a triangular prism, the *ovary*, three roughened scroll-like objects at

[1] Best seen in a flower which is just opening.

the top, and three lobes of the *stigma*. Make a sketch of these parts about twice natural size, and label them × 2. Touch a small camel's-hair pencil to one of the anthers, and then transfer the pollen thus removed to the stigma. This operation is merely an imitation of the work done by insects which visit the flowers out of doors. Does the pollen cling readily to the rough stigmatic surface? Examine this adhering pollen with the two-inch objective, and sketch a few grains of it, together with the bit of the stigma to which it clings. Compare this drawing with Fig. 121. Make a cross-section of the ovary about midway of its length, and sketch the section as seen through the magnifying glass. Label the three chambers shown *cells of the ovary*[1] or *locules*, and the white egg-shaped objects within *ovules*.[2]

Make a longitudinal section of another ovary, taking pains to secure a good view of the ovules, and sketch as seen through the magnifying glass.

Making use of the information already gained and the cross-section of the ovary as sketched, construct a diagram of a cross-section of the entire flower on the same general plan as those shown in Fig. 116.[3]

Split a flower lengthwise[4] and construct a longitudinal section of the entire flower on the plan of those shown in Fig. 114, but showing the contents of the ovary.

174. The Flower of the Buttercup. — Make a diagram of the mature flower as seen in a side view, looking a little down into it. Label the pale greenish-yellow, hairy, outermost parts *sepals*, and the larger bright yellow parts above and within these *petals*, and the yellow-knobbed parts which occupy a good deal of the interior of the flower *stamens*.

Note the difference in the position of the sepals of a newly opened flower and that of the sepals of a flower which has opened as widely as possible. Note the way in which the petals are arranged in relation

[1] Notice that the word *cell* here means a comparatively large cavity, and is not used in the same sense in which we speak of a wood-cell or a pith-cell.

[2] The section will be more satisfactory if made from an older flower, grown out of doors, from which the perianth has fallen. In this case label the contained objects *seeds*.

[3] Consult also the footnote to Sect. 172.

[4] One will do for an entire division of the class.

to the sepals. In an opening flower observe the arrangement of the edges of the petals, — how many entirely outside the others, how many entirely inside, how many with one edge in and the other out.

Cut off a sepal and a petal, each close to its attachment to the flower; place both, face down, on a sheet of paper, and sketch about twice the natural size and label it × 2. Describe the difference in appearance between the outer and the inner surface of the sepal and of the petal. Note the little scale at the base of the petal, inside.

Strip off all the parts from a flower which has lost its petals, until nothing is left but a slender conical object a little more than an eighth of an inch in length. This is the *receptacle* or summit of the peduncle.

In a fully opened flower note the numerous yellow-tipped *stamens*, each consisting of a short stalk, the *filament*, and an enlarged yellow knob at the end, the *anther*. Note the division of the anther into two portions, which appear from the outside as parallel ridges, but which are really closed tubes, the *anther-cells*.

Observe in the interior of the flower the somewhat globular mass (in a young flower almost covered by the stamens). This is a group of *pistils*. Study one of these groups in a flower from which the stamens have mostly fallen off, and make an enlarged sketch of the head of pistils. Remove some of the pistils from a mature head, and sketch a single one as seen with the magnifying glass. Label the little knob or beak at the upper end of the pistil *stigma*, and the main body of the pistil the *ovary*. Make a section of one of the pistils, parallel to the flattened surfaces, like that shown in Fig. 136, and note the partially matured seed within.[1]

[1] After Chapter XV has been completed the teacher may find it advisable to dictate additional studies of some highly irregular flowers.

CHAPTER XV

PLAN AND STRUCTURE OF THE FLOWER AND ITS ORGANS

175. Parts or Organs of the Flower. — Most showy flowers consist, like those studied in the preceding chapter, of four circles or sets of organs, — the sepals, petals, stamens, and pistils. The sepals taken together constitute the *calyx;* the petals taken together constitute the *corolla* (Fig. 97).[1] Sometimes it is convenient to have a word to comprise both calyx and corolla; for this the term *perianth* is used. A flower which contains all four of these sets is said to be *complete.* Since the work of the flower is to produce seed, and seed-forming is due to the coöperation of stamens and pistils, or, as they are often called from their relation to the reproductive organs of spore-plants, *microsporophylls* and *macrosporophylls* (see Sect. 336), these are known as the *essential organs.* The simplest possible pistil is a dwarfed

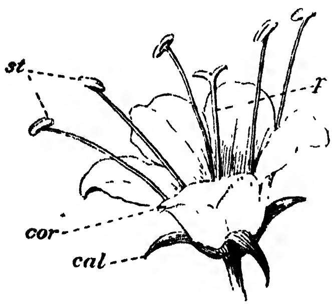


FIG. 97. The Parts of the Flower.
cal, calyx; *cor*, corolla; *st*, stamens; *p*, pistil.

[1] The flower of the waterleaf, *Hydrophyllum canadense*, modified by the omission of the hairs on the stamens, is here given because it shows so plainly the relation of the parts.

and greatly modified leaf (Sect. 189) adapted into a seed-bearing organ. Such a pistil may be one-seeded, as in Fig. 136, or several-seeded, as in Fig. 138; it is called a *carpel.* The calyx and corolla are also known as the *floral envelopes.* Flowers which have the essential organs are called *perfect flowers.* They may, therefore, be perfect without being complete. Incomplete flowers with only one row of parts in the perianth are said to be *apetalous* (Fig. 98).

176. Regular and Symmetrical Flowers. — A flower is *regular* if all the parts of the same set or circle are alike in size and shape, as in the stonecrop (Fig. 99). Such flowers as that of the violet, the monkshood, and the sweet pea (Fig. 100) are irregular. *Symmetrical* flowers are those whose calyx, corolla, circle of stamens, and set of carpels consist each of the same number of parts, or in which the number in every case is a multiple of the smallest number found in any set. The stonecrop is symmetrical, since it has five sepals, five petals, ten stamens, and five carpels. Roses, mallows, and mignonette are familiar examples of flowers which are unsymmetrical because they have a large, indefinite number of stamens; the portulaca is unsymmetrical, since it has two divisions of the calyx, five or six petals, and seven to twenty stamens.

FIG. 98. Apetalous Flower of (European) Wild Ginger.

177. The Receptacle. — The parts of the flower are borne on an expansion of the peduncle called the *receptacle.* Usually, as in the flower of the grape (Fig. 127), this is only a slight enlargement of the peduncle, but in the lotus and the magnolia the receptacle is of great size, particularly

after the petals have fallen and the seed has ripened. The receptacle of the rose (Fig. 101) is hollow and the pistils arise from its interior surface.

178. Imperfect or Separated Flowers. — The stamens and pistils may be produced in separate flowers, which

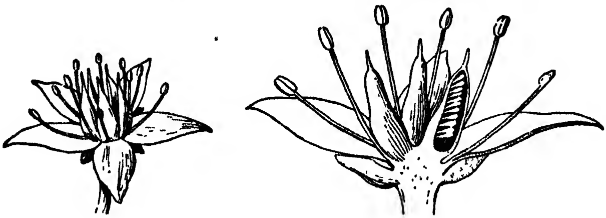


Fig. 99. Flower of Stonecrop.
I, entire flower (magnified). II, vertical section (magnified).

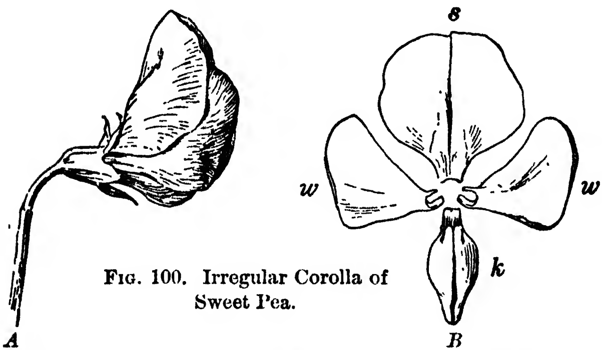


Fig. 100. Irregular Corolla of Sweet Pea.

A, side view; *B*, front view. *s*, standard; *w*, *w*, wings; *k*, keel.

are of course *imperfect.* This term does not imply that such flowers do their work any less perfectly than others, but only that they have not both kinds of essential organs. In the very simple imperfect flowers of the willow (Fig. 102) each flower of the catkin (Appendix, Fig. 6) consists

merely of a pistil or a group of (usually two) stamens springing from the axil of a small bract.

Staminate and pistillate flowers may be borne on different plants, as they are in the willow, or they may be borne on the same plant, as in the hickory and the hazel, among trees, or in the castor-oil plant, Indian corn, and the begonias. When staminate and pistillate flowers are borne on separate plants, such

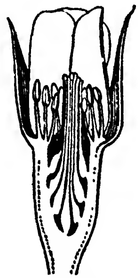


FIG. 101.

A Rose, Longitudinal Section.

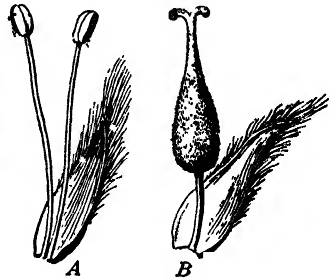


FIG. 102.

Flowers of Willow. (Magnified.) *A*, staminate flower; *B*, pistillate flower.

a plant is said to be *diœcious*, that is, of two households; when both kinds of flower appear on the same individual, the plant is said to be *monœcious*, that is, of one household.

179. Study of Imperfect Flowers. — Examine, draw, and describe the imperfect flowers of some of the following diœcious plants and one of the monœcious plants.[1]

Diœcious plants	early meadow rue. willow. poplar.
Monœcious plants	walnut, oak, chestnut. hickory, alder, beech. birch, hazel, begonia.

[1] For figures or descriptions of these or allied flowers, consult Gray's *Manual of Botany*, Emerson's *Trees and Shrubs of Massachusetts*, Newhall's *Trees of the Northern United States*, or Le Maout and Decaisne's *Traité Général de Botanique*.

180. Union of Similar Parts of the Perianth. — The sepals may appear to join or *cohere* to form a calyx which is more or less entirely united into one piece, as in Figs. 97 and 100. In this case the calyx is said to be *gamosepalous*, that is, of wedded sepals. In the same way the corolla is frequently *gamopetalous*, as in Figs. 103–107. Frequently the border or *limb* of the calyx or corolla is more or less cut or lobed. In this case the projecting portions of the limb are known as divisions, teeth, or lobes.[1] Special names of great use in accurately describing plants are given

FIG. 103.
Bell-Shaped Corolla of Bell-Flower (*Campanula*).

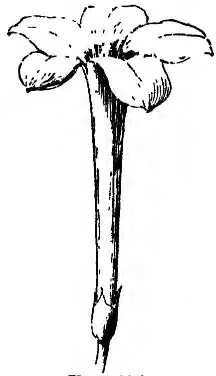


FIG. 104.
Salver-Shaped Corolla of Jasmine. (Magnified.)

FIG. 105.
Wheel-Shaped Corolla of Potato.

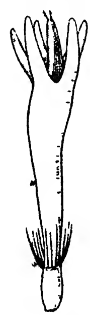


FIG. 106.
Tubular Corolla, from Head of Bachelor's Button.

FIG. 107.
Labiate or Ringent Corolla of Dead Nettle.

[1] It would not be safe to assume that the gamosepalous calyx or the gamopetalous corolla is really formed by the union of separate portions, but it is very convenient to speak of it as if it were.

to a large number of forms of the gamopetalous corolla. Only a few of these names are here given in connection with the figures.

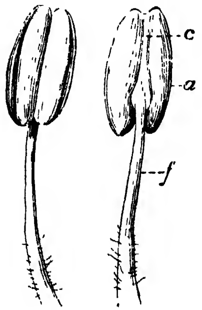


FIG. 108. Parts of a Stamen.

A, front; *B*, back. *a*, anther; *c*, connective; *f*, filament.

When the parts of either circle of the perianth are wholly unconnected with each other, that is, polysepalous or polypetalous, such parts are said to be *distinct*.

181. Parts of the Stamen and the Pistil. — The stamen usually consists of a hollow portion, the *anther* (Fig. 108, *a*), borne on a stalk called the *filament* (Fig. 108, *f*), which is often lacking. Inside the anther is a powdery or pasty substance called *pollen* or *microspores* (Sect. 336). The pistil usually consists of a small chamber, the *ovary*, which contains the *ovules*, *macrospores* (Sect. 336), or rudimentary seeds, a slender portion or stalk, called the *style*, and at the top of this a ridge, knob, or point called the *stigma*. These parts are all shown in Fig. 109. In many pistils the stigma is borne directly on the ovary.

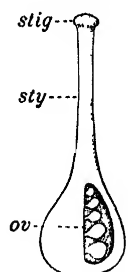


FIG. 109. Parts of the Pistil.

ov, ovary; *sty*, style; *stig*, stigma.

182. Union of Stamens with Each Other. — Stamens may be wholly unconnected with each other or *distinct*, or they may cohere by their filaments into a single group, when they are said to be *monadelphous*, of one brotherhood (Fig. 110), into two groups (*diadelphous*) (Fig. 112), or into many groups. In some flowers the stamens are held together in a ring by their coherent anthers (Fig. 111).

183. Union of Pistils. — The pistils may be entirely separate from each other, *distinct* and *simple*, as they are in the buttercup and the stonecrop, or several may join to form one *compound pistil* of more or less united carpels. In the latter case the union generally affects the ovaries, but often leaves the styles separate, or it may result in joining ovaries and styles, but leave the stigmas separate or at any rate lobed, so as to show of how many separate carpels the compound pistil is made up. Even when there is no external sign to show the compound nature of the pistil, it can usually be recognized from the study of a cross-section of the ovary.

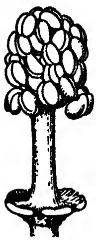


FIG. 110. Monadelphous Stamens of Mallow.

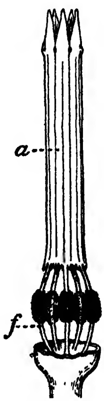


FIG. 111. Stamens of a Thistle, with Anthers united into a Ring.

a, united anthers; *f*, filaments, bearded on the sides.

184. Cells of the Ovary; Placentas. — Compound ovaries are very commonly several-celled, that is, they consist of a number of separate cells[1] or chambers more scientifically known as *locules*. Fig. 113, *B*, shows a three-celled ovary seen in cross-section. The ovules are not borne indiscriminately by any part of the lining of the ovary. In one-celled pistils they frequently grow in a line running along one side of the ovary, as in the pea pod (Fig. 146).

[1] Notice that the word *cell* is here used in an entirely different sense from that in which it has been employed in the earlier chapters of this book. As applied to the ovary it means a chamber or compartment.

The ovule-bearing line is called a *placenta;* in compound pistils there are commonly as many placentas as there are separate pistils joined to make the compound one. Placentas on the wall of the ovary, like those in Fig. 113, *A*, are called *parietal placentas;* those which occur as at *B*, in the same figure, are said to be central; and those which, like the form represented in *C* of the same figure, consist of a column rising from the bottom of the ovary are called *free central placentas.*

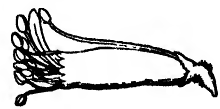


FIG. 112. Diadelphous Stamens of Sweet Pea.

185. Union of Separate Circles. — The members of one of the circles of floral organs may join those of another circle, thus becoming *adnate*, *adherent*, or *consolidated.* In Fig. 98 the calyx tube is adnate to the ovary. In this case the parts of the flower do not all appear to spring from the receptacle. Fig. 114 illustrates three common cases as regards insertion of the parts of the flower. In I they are all inserted on the receptacle, and the corolla and stamens are said to be *hypogynous*, that is, beneath the pistil. In II the petals and the stamens appear as if they had grown fast to the calyx for some distance, so that they surround the pistil, and they are therefore said to be *perigynous*, that is, around the pistil. In III all the parts are *free* or unconsolidated except the petals and stamens; the stamens may be described as *epipetalous*, that is, growing on the petals. Sometimes some or all of the other parts

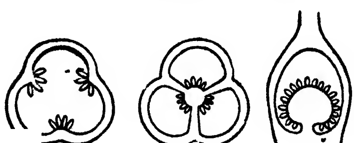


FIG. 113. Principal Types of Placenta.
A, parietal placenta; *B*, central placenta; *C*, free central placenta; *A* and *B*, transverse sections; *C*, longitudinal section.

stand upon the ovary, and such parts are said to be *epigynous*, that is, on the ovary, like the petals and stamens of the white water-lily (Fig. 115).

186. Floral Diagrams. — Sections (real or imaginary) through the flower lengthwise, like those of Fig. 114, help greatly in giving an accurate idea of the relative position of the floral organs. Still more important in this way are cross-sections, which may be recorded in diagrams like those of Fig. 116.[1] In constructing such diagrams it will often be necessary to suppose some of the parts of the flower to be raised or lowered from their true position so as to bring them into such relations that all could be cut by a single section. This would, for instance, be necessary in making a diagram for the cross-section of the flower of the white water-lily, of which a partial view of one side is shown in Fig. 115.[2]

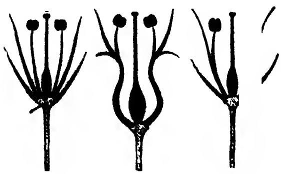


FIG. 114. Insertion of the Floral Organs.

I, hypogynous, all the other parts on the receptacle, beneath the pistil; II, perigynous, petals and stamens apparently growing out of the calyx, around the pistil; III, corolla hypogynous, stamens epipetalous.

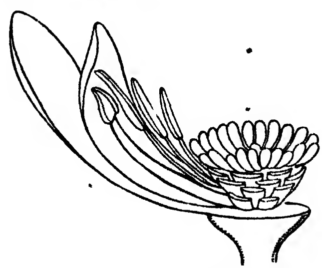
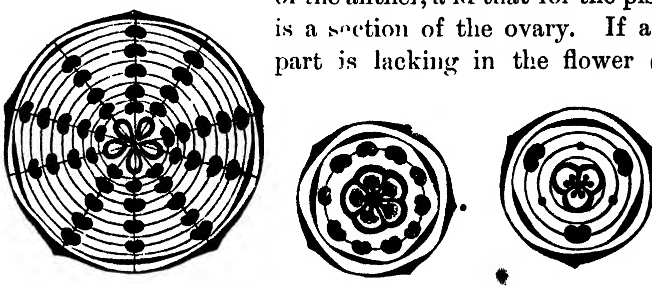


FIG. 115. White Water-Lily. The inner petals and the stamens growing from the ovary.

[1] For floral diagrams see Le Maout and Decaisne's *Traité Général de Botanique*, or Eichler's *Blüthendiagramme*.

[2] It is best to begin practice on floral diagrams with flowers so firm and large that actual sections of them may be cut with ease and the relations of the parts in the section readily made out. The tulip is admirably adapted to this purpose.

Construct diagrams of the longitudinal section and the transverse section of several large flowers, following the method indicated in Figs. 114 and 116, but making the longitudinal section show the interior of the ovary.[1] It is found convenient to distinguish the sepals from the petals by representing the former with midribs. The diagrammatic symbol for a stamen stands for a cross-section of the anther, and that for the pistil is a section of the ovary. If any part is lacking in the flower (as



I II III

FIG. 116. Diagram of Cross-Sections of Flowers.

I columbine, II, heath family; III, iris family. In each diagram the dot alongside the main portion indicates a cross-section of the stem of the plant. In II every other stamen is more lightly shaded, because some plants of the heath family have five and some ten stamens.

in the case of flowers which have some antherless filaments), the missing or abortive organ may be indicated by a dot. In the diagram of the iris family (Fig. 116, III) the three dots inside the flower indicate the position of a second circle of stamens, found in most flowers of monocotyledons but *not* found in this family.

[1] Among the many excellent early flowers for this purpose may be mentioned trillium, bloodroot, dogtooth violet, marsh marigold, buttercup, tulip tree, horse-chestnut, Jeffersonia, May-apple, cherry, apple, crocus, tulip, daffodil, primrose, wild ginger, cranesbill, locust, bluebell.

187. Review Summary of Chapter XV.[1]

Kinds of flowers as regards number of circles or sets of organs present	1. 2. 3. 4.
Kinds as regards numerical plan	1. 2.
Kinds as regards similarity of parts of the same circle	1. 2.
Parts of a stamen	1. 2.
Parts of a pistil	1. 2. 3.
Stamens as regards union with each other	1. 2. 3. 4.
Pistils as regards union with each other	1. 2.
Degree of union of separate circles	

[1] Illustrate by sketches.

CHAPTER XVI

TRUE NATURE OF FLORAL ORGANS; DETAILS OF THEIR STRUCTURE; FERTILIZATION

188. The Flower a Shortened and greatly Modified Branch. — In Chapter IX the leaf-bud was explained as being an undeveloped branch, which in its growth would develop into a real branch (or a prolongation of the main stem). Now, since flower-buds appear regularly either in the axils of leaves or as terminal buds, there is reason to regard them as of similar nature to leaf-buds.

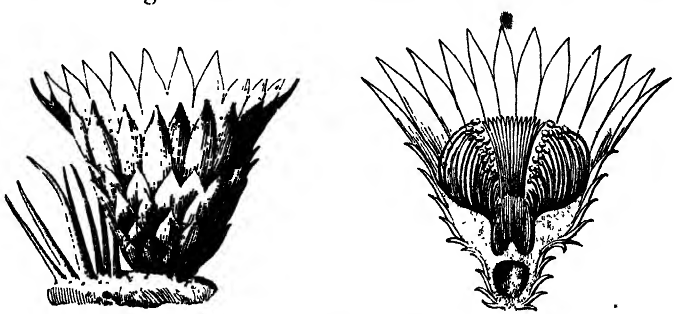


FIG. 117. Transition from Bracts to Sepals in a Cactus Flower.

This would imply that the receptacle corresponds to the axis of the bud shown in Fig. 55, and that the parts of the flower correspond to leaves. There is plenty of evidence that this is really true. Sepals frequently look

very much like leaves, and in many cactuses the bracts about the flower are so sepal-like that it is impossible to tell where the bracts end and the sepals begin (Fig. 117). The same thing is true of sepals and petals in such flowers as the white water-lily. In this flower there is a remarkable series of intermediate steps, ranging all the way from petals, tipped with a bit of anther, through stamens with a broad petal-like filament, to regular stamens, as is shown

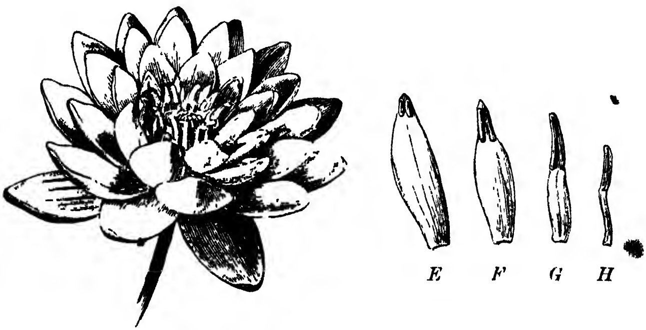


FIG. 118. Transitions from Petals to Stamens in White Water-Lily.

E, F, G, H, various steps between petal and stamen.

in Fig. 118, *E, F, G, H.* The same thing is shown in many double roses. In completely double flowers all the *essential* organs are transformed by cultivation into petals. In the flowers of the cultivated double cherry the pistils occasionally take the form of small leaves, and some roses turn wholly into green leaves.

Summing up, then, we know that flowers are altered and shortened branches: (1) because flower-buds have, as regards position, the same kind of origin as leaf-buds; (2) because all the intermediate steps are found between

bracts, on the one hand, and stamens, on the other; (3) because the essential organs are found to be replaced by petals or even by green leaves.

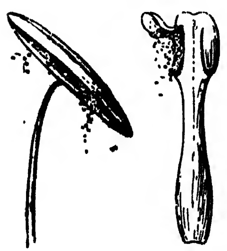
The fact that leaves should be so greatly modified as they are in flowers and given work to do wholly different from that of the other kinds of leaves so far studied need not strike one as exceptional. In many of the most highly developed plants below the seed-plants, organs corresponding to flowers are found, and these consist of modified leaves set apart for the work of reproducing.

189. Mode of Formation of Stamens and Pistils from Leaves. — It is hardly possible to state, until after Chapter XXVI has been studied, how stamens stand related to leaves.[1]

The simple pistil or *carpel* is supposed to be made on the plan of a leaf folded along the midrib until its margins touch, like the cherry leaf in Fig. 56. But the student must not understand by this statement that the little pistil leaf grows at first like an ordinary leaf and finally becomes folded in. The united leaf-margins near the tip would form the stigma, and the placenta would correspond to the same margins, rolled slightly inwards, extending along the inside of the inflated leaf-pouch. Place several such folded leaves upright about a common center, and their cross-section would be much like that of *B* in Fig. 113. Evidence that carpels are really formed in this way may be gained from the study of such fruits as that of the monkshood (Fig. 138), in which the ripe carpels may be seen to unfold into a shape much more leaf-like than

[1] "The anther answers exactly to the spore-cases of the ferns and their allies, while the filament is a small specialized leaf to support it." For a fuller statement, see Potter and Warming's *Systematic Botany*, pp. 236, 237.

that which they had while the pistil was maturing. What really occurs is this: the flower-bud, as soon as it has developed far enough to show the first rudiments of the essential organs, contains them in the form of minute knobs. These are developed from the tissues of the plant in the same manner as are the knobs in a leaf-bud, which afterwards become leaves (Fig. 57, *B*); but as growth and development progress in the flower-bud, its contents soon show themselves to be stamens and pistils (if the flower is a perfect one).



I II III

Fig. 119. Modes of discharging Pollen.

I, by longitudinal slits in the anther-cells (amaryllis); II, by uplifted valves (barberry); III, by a pore at the top of each anther-lobe (nightshade).

190. The Anther and its Contents.—Some of the shapes of anthers may be learned from Figs. 108 and 119.[1] The shape of the anther and the way in which it opens depend largely upon the way in which the pollen is to be discharged and how it is carried from flower to flower. The commonest method is to have the anther-cells split lengthwise, as in Fig. 119, I. A few anthers open by trap-doors like valves, as in II, and a larger number by little holes at the top, as in III.

The pollen in many plants with inconspicuous flowers, as the evergreen cone-bearing trees, the grasses, rushes, and sedges, is a fine, dry powder. In plants with showy flowers it is often somewhat sticky or pasty. The forms of pollen grains are extremely various. Fig. 120 will

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. II, pp. 86–95.

serve to furnish examples of some of the shapes which the grains assume; *c* in the latter figure is perhaps as common a form as any. Each pollen grain consists mainly of a single cell, and is covered by a moderately thick outer wall and a thin inner one. Its contents are thickish protoplasm, full of little opaque particles, and usually containing grains of starch and little drops of oil. The knobs on the outer coat, as shown in Fig. 120, *b*, mark

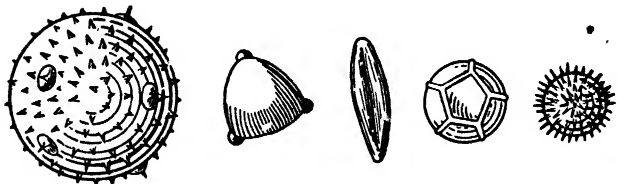


FIG. 120. Pollen Grains. (Very greatly magnified.)

a, pumpkin; *b*, enchanter's nightshade; *c*, Albuca; *d*, pink; *e*, hibiscus.

the spots at which the inner coat of the grain is finally to burst through the outer one, pushing its way out in the form of a slender, thin-walled tube.[1]

191. The Formation of Pollen Tubes. — This can be studied in pollen grains which have lodged on the stigma and there been subjected to the action of its moist surface. It is, however, easier to cause the artificial production of the tubes.

EXPERIMENT XIX

Production of Pollen Tubes. — Place a few drops of suitably diluted syrup with some fresh pollen in a concave cell ground in a microscope slide; cover with a thin glass circle; place under a bell-glass, with a wet cloth or sponge to prevent evaporation of the syrup, and set

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. II, pp. 95–104.

aside in a warm place, or merely put some pollen in syrup in a watch crystal under the bell-glass. Examine from time to time to note the appearance of the pollen tubes. Try several kinds of pollen if possible, using syrups of various strengths. The following kinds of pollen form tubes readily in syrups of the strengths indicated.

Tulip	1 to 3 per cent.
Narcissus	3 to 5 "
Cytisus canariensis (called Genista by florists)	15 "
Chinese primrose	10 "
Sweet pea[1]	10 to 15 "
Tropæolum[1]	15 "

192. Microscopical Structure of the Stigma and Style. — Under a moderate power of the microscope the stigma is seen to consist of cells set irregularly over the surface, and secreting a moist liquid to which the pollen grains adhere (Fig. 121). Beneath these superficial cells and running down through the style (if there is one) to the ovary is spongy parenchyma. In some pistils the pollen tube proceeds through the cell-walls, which it softens by means of a substance which it exudes for that purpose. In other cases (Fig. 122) there is a canal or passage along which the pollen tube travels on its way to the ovule.

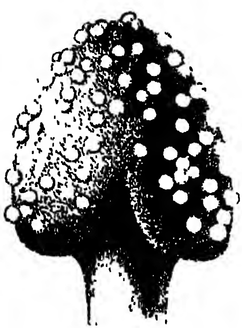


FIG. 121. Stigma of Thorn-Apple (*Datura*) with Pollen. (Magnified.)

[1] The sweet-pea pollen and that of tropæolum are easier to manage than any other kinds of which the author has personal knowledge. If a concaved slide is not available, the cover-glass may be propped up on bits of the thinnest broken cover-glasses. From presence of air or some other reason, the formation of pollen tubes often proceeds most rapidly just inside the margin of the cover-glass.

193. Fertilization. — By fertilization in seed-plants the botanist means the union of a generative cell from a pollen grain with that of an egg-cell at the apex of the *embryo sac* (Fig. 124). This process gives rise to a cell which contains material derived from the pollen and from the egg-cell. In a great many plants the pollen, in order to accomplish the most successful fertilization, must come from another plant of the same kind, not from the individual which bears the ovules that are being fertilized.

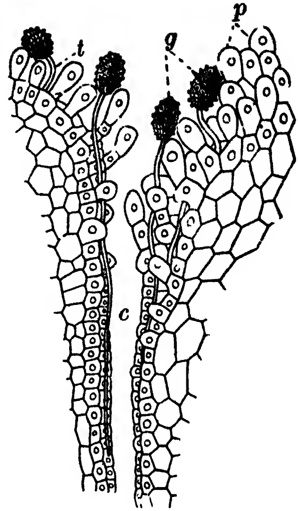


Fig. 122. Pollen Grains producing Tubes, on Stigma of a Lily. (Much magnified.)

g, pollen grains; *t*, pollen tubes; *p*, papillæ of stigma; *c*, canal or passage running toward ovary.

Pollen tubes begin to form soon after pollen grains lodge on the stigma. The time required for the process to begin varies in different kinds of plants, requiring in many cases twenty-four hours or more. The length of time needed for the pollen tube to make its way through the style to the ovary depends upon the length of the style and other conditions. In the crocus, which has a style several inches long, the descent takes from one to three days.

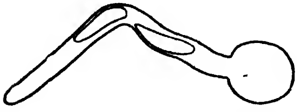


Fig. 123. Pollen Grain of Snowflake (*Leucoium*) producing a Pollen Tube with Two Naked Generative Cells.

Finally the tube penetrates the opening at the apex of the

ovule *m*, in Fig. 124, reaches one of the cells shown at *e*, and transfers a generative cell into this egg-cell. The latter is thus enabled to divide and grow rapidly into an embryo. This the cell does by forming cell-walls and then increasing by continued subdivision in much the same way in which the cells at the growing point near the tip of the root subdivide.[1]

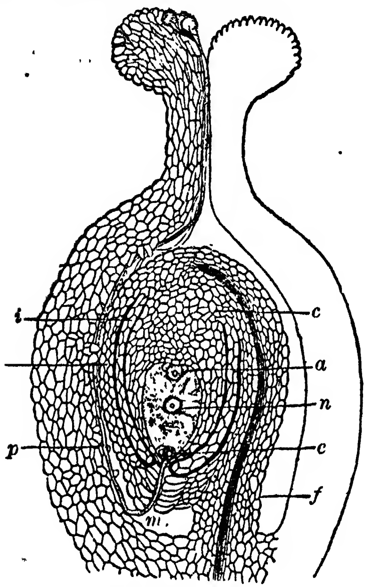


FIG. 124. Diagrammatic Representation of Fertilization of an Ovule.

i, inner coating of ovule; *o*, outer coating of ovule; *p*, pollen tube, proceeding from one of the pollen grains on the stigma; *c*, the place where the two coats of the ovule blend (the kind of ovule here shown is inverted, its opening *m* being at the bottom, and the stalk *f* adhering along one side of the ovule); *a* to *e*, embryo sac, full of protoplasm; *a*, so-called antipodal cells of embryo sac; *n*, central nucleus of the embryo sac; *e*, nucleated cells, one of which, the egg-cell, receives the essential contents of the pollen tube; *f*, funiculus or stalk of ovule; *m*, opening into the ovule.

194. Nature of the Fertilizing Process. — The necessary feature of the process of fertilization is *the union of the essential contents of two cells to form a new one from which the future plant is to spring.* This kind of union is found to occur in many cryptogams (Chapters XXIII–XXV), resulting in the production of a spore capable of growing into a complete plant.

[1] See Strasburger, Noll, Schenk and Schimper's *Text-Book of Botany*, pp. 442–446.

195. Number of Pollen Grains to Each Ovule. — Only one pollen tube is necessary to fertilize each ovule, but so many pollen grains are lost that plants produce many more of them than of ovules. The ratio, however, varies greatly. In the night-blooming cereus there are about 250,000 pollen grains for 30,000 ovules, or rather more than 8 to 1, while in the common garden wistaria there are about 7000 pollen grains to every ovule, and in Indian corn, the cone-bearing evergreens, and a multitude of other plants, many times more than 7000 to 1. These differences depend upon the mode in which the pollen is carried from the stamens to the pistil.

CHAPTER XVII

ECOLOGY OF FLOWERS; POLLINATION

196. Topics of the Chapter. — The ecology of flowers is concerned mainly with the means by which the transference of pollen or *pollination* is effected, and with the ways in which pollen is kept away from undesirable insect visitors and from rain.

197. Cross-Pollination and Self-Pollination.—It was long supposed by botanists that the pollen of any perfect flower needed only to be placed on the stigma of the same flower to insure satisfactory fertilization. At present it is known that probably nearly all attractive flowers, even if they can produce some seed when self-pollinated, do far better when pollinated from the flowers of another plant of the same kind.[1] This important fact was established by a long series of experiments on the number and vitality of seeds produced by a flower when treated with its own pollen, or *self-pollinated*, and when treated with pollen from another flower of the same kind, or *cross-pollinated*.[2]

198. Wind-Pollinated Flowers.[3] — It has already been mentioned that some pollen is dry and powdery and other kinds are more or less sticky. Pollen of the dusty sort is light, and therefore adapted to be blown about by the

[1] See Darwin's *Cross and Self-Fertilization in the Vegetable Kingdom* (especially Chapters I and II).

[2] On dispersion of pollen see Kerner and Oliver, Vol. II, pp. 129–287.

[3] See Newell's *Reader in Botany*, Part II, Chapter VII.

wind. Any one who has been much in cornfields after the corn has "tasseled" has noticed the pale yellow dusty pollen which flies about when a cornstalk is jostled, and which collects in considerable quantities on the blades of the leaves. Corn is monœcious, but fertilization is best accomplished by pollen blown from the "tassel" (stamens) of one plant to the "silk" (pistils) of another plant. The pistil of wind-pollinated flowers is often feathery and thus adapted to catch flying pollen-grains (Fig. 125). Other characteristics of such flowers are the inconspicuous character of their perianth, which is usually green or greenish, the absence of odor and of nectar, the regularity of the corolla, and the appearance of the flowers before the leaves or their occurrence on stalks raised above the leaves.

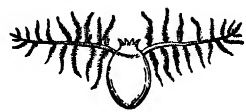


Fig. 125. Pistil of a Grass, provided with a Feathery Stigma, adapted for Wind-Pollination.

Pollen is, in the case of a few aquatic plants, carried from flower to flower by the water on which it floats.

199. Insect-Pollinated Flowers. — Most plants which require cross-pollination depend upon insects as pollen-carriers,[1] and it may be stated as a general fact that the showy colors and markings of flowers and their odors all serve as so many advertisements of the nectar (commonly but wrongly called honey) or of the nourishing pollen which the flower has to offer to insect visitors.

200. Pollen-Carrying Apparatus of Insects.[2] — Ants and some beetles which visit flowers have smooth bodies to which little pollen adheres, so that their visits are often of

[1] A few are pollinated by snails; many more by humming-birds and other birds.

[2] See P. Knuth, *Handbuch der Blüthenbiologie.*

slight value to the flower; but many beetles, all butterflies and moths, and most bees have bodies roughened with scales or hairs which hold a good deal of pollen entangled.

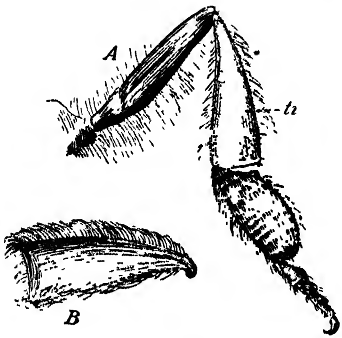


FIG. 126.

A, right hind leg of a honey-bee (seen from behind and within); *B*, the tibia. *ti*, seen from the outside, showing the collecting basket formed of stiff hairs.

In the common honey-bee (and in many other kinds) the greater part of the insect is hairy, and there are special collecting baskets, formed by bristle-like hairs, on the hind legs (Fig. 126). It is easy to see the load of pollen accumulated in these baskets after such a bee has visited several flowers. Of course the pollen which the bee packs in the baskets and carries off to the hive, to be stored for food, is of no use in pollination.

201. Nectar and Nectaries. — Nectar is a sweet liquid which flowers secrete for the purpose of attracting insects. After partial digestion in the crop of the bee, nectar becomes honey. Those flowers which secrete nectar do so by means of *nectar glands*, small organs whose structure is something like that of the stigma, situated often near the base of the flower, as shown in Fig. 127. Sometimes the nectar clings in droplets to the surface of the nectar glands; sometimes it is stored in little cavities or pouches called *nectaries*. The pouches at the bases of columbine petals are among the most familiar of nectaries.

202. Odors of Flowers. — The acuteness of the sense of smell among insects is a familiar fact. Flies buzz about the

wire netting which covers a piece of fresh meat or a dish of syrup, and bees, wasps, and hornets will fairly besiege the window screens of a kitchen where preserving is going on. Many plants find it possible to attract as many insect visitors as they need without giving off any scent, but small flowers, like the mignonette, and night-blooming ones, like the white tobacco and the evening primrose, are sweet-scented to attract night-flying moths. It is interesting to observe that the majority of the flowers which bloom at night are white, and that they are much more generally sweet-scented than flowers which bloom during the day. A few flowers are carrion-scented (and purplish or brownish colored) and attract flies.

203. Colors of Flowers. — Flowers which are of any other color than green probably in most cases display their colors to attract insects, or occasionally birds.

It is certain, however, that colors are less important means of attraction than odors, from the fact that insects are extremely near-sighted. Butterflies and moths cannot see distinctly at a distance of more than about five feet, bees and wasps at more than two feet, and flies at more than two and a fourth feet. Probably no insects can make out objects clearly more than six feet away;[1] yet it is quite possible that their attention is attracted by colors at distances greater than those mentioned.[2]

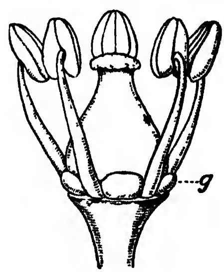


Fig. 127. Stamens and Pistil of the Grape (magnified), with a Nectar Gland, *g*, between Each Pair of Stamens.

[1] See Packard's *Text-Book of Entomology*, p. 260.

[2] See Lubbock's *Flowers, Fruits, and Leaves*, Chapter II. On the general subject of colors and odors in relation to insects, see P. Knuth, *Handbuch der Blüthenbiologie*.

204. Nectar Guides. — In a large number of cases the petals of flowers show decided stripes or rows of spots of a color different from that of most of the petal. These commonly lead toward the nectaries, and it is possible that such markings point out to insect visitors the way to the nectaries. Following this course, the insect not only secures the nectar which he seeks, but probably leaves pollen on the stigma and becomes dusted with new pollen, which he carries to another flower.

FIG. 128. A Beetle on the Flower of the Twayblade. (Enlarged three times.)

205. Facilities for Insect Visits. — Regular polypetalous flowers have no special adaptations to make them singly accessible to insects, but they lie open to all comers. Irregular flowers probably always are more or less adapted to particular insect (or other) visitors. The adaptations are extremely numerous; here only a very few of the simpler ones will be pointed out.[1] Where there is a drooping lower petal (or, in the case of a gamopetalous corolla, a lower lip), this serves as a perch upon which flying insects may alight and stand while they explore the flower, as the beetle is doing in Fig. 128. In Fig. 129 one bumblebee stands with his legs partially encircling the lower lip of the dead-nettle flower, while another perches on the sort of grating made by the stamens of the horse-chestnut flower. The honey-bee entering the violet clings to the beautifully bearded portion of the two lateral petals while it sucks the nectar from the *spur* beneath.

[1] See P. Knuth, *Handbuch der Blüthenbiologie*.

Plate X. Pollination of Thistle Flowers by Butterflies.

206. Protection of Pollen from Unwelcome Visitors. — It is usually desirable for the flower to prevent the entrance of small creeping insects, such as ants, which carry little pollen and eat a relatively large amount of it. The means adopted to secure this result are many and curious. In some plants, as the common catchfly, there is a sticky

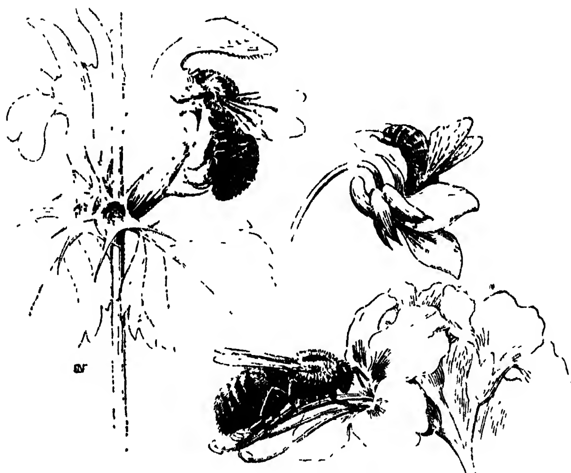


FIG. 120. Bees visiting Flowers.

At the left, a bumblebee on the flower of the dead nettle; below, a similar bee in the flower of the horse-chestnut; above, a honey-bee in the flower of a violet.

ring about the peduncle, some distance below the flowers, and this forms an effectual barrier against ants and like insects. Very frequently the calyx tube is covered with hairs, which are sometimes sticky.

Sometimes the recurved petals or divisions of the corolla stand in the way of creeping insects. In other cases the throat of the corolla is much narrowed or closed by hairs

or by appendages.[1] Those flowers which have one or more sepals or petals prolonged into spurs, like the nasturtium and the columbine, are inaccessible to most insects except those which have a tongue or a sucking-tube long

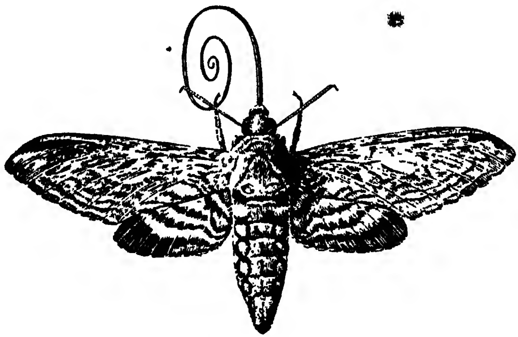


FIG. 130. A Sphinx Moth with a Long Sucking-Tube.

enough to reach to the nectary at the bottom of the spur. The large sphinx moth, shown in Fig. 130, which is a common visitor to the flowers of the evening primrose, is an example of an insect especially adapted to reach deep into long tubular flowers.

207. Bird-Pollinated Flowers.—Some flowers with very long tubular corollas depend entirely upon birds to carry their pollen for them. Among garden flowers the gladiolus, the scarlet salvia, and the trumpet honeysuckle are largely dependent upon humming-birds for their pollination. The wild balsam or jewel-weed and the trumpet-creeper are also favorite flowers of the humming-bird.

208. Prevention of Self-Fertilization.—Diœcious flowers are of course quite incapable of self-pollination. Pistillate

[1] On protection of pollen, see Kerner and Oliver, Vol. II, pp. 95–109.

monœcious flowers may be pollinated by staminate ones on the same plant, but this does not secure as good seed as is secured by having pollen brought to the pistil from a different plant of the same kind.

In perfect flowers self-pollination would commonly occur unless it were prevented by the action of the essential organs or by something in the structure of the flower. In reality many flowers which at first sight would appear to be designed to secure self-pollination are almost or quite incapable of it. Frequently the pollen from another plant of the same species prevails over that which the flower may shed on its own pistil, so that when both kinds are placed on the stigma at the same time it is the foreign pollen which causes fertilization. But apart from this fact there are several means of insuring the presence of foreign pollen, and only that, upon the stigma, just when it is mature enough to receive pollen tubes.

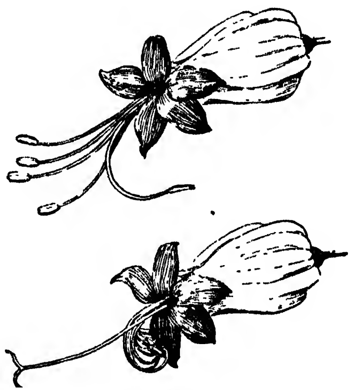


FIG. 131. Flower of *Clerodendron* in Two Stages.

In *A* (earlier stage) the stamens are mature, while the pistil is still undeveloped and bent to one side. In *B* (later stage) the stamens have withered and the stigmas have separated, ready for the reception of pollen.

209. Stamens and Pistils maturing at Different Times. — If the stamens mature at a different time from the pistils, self-pollination is as effectually prevented as though the plant were diœcious. This unequal maturing or *dichogamy*

occurs in many kinds of flowers. In some, the figwort and the common plantain for example, the pistil develops before the stamens, but usually the reverse is the case. The *Clerodendron*,[1] a tropical African flower (Fig. 131), illustrates in a most striking way the development of stamens before the pistil. The insect visitor, on its way to the nectary, can hardly fail to brush against the protruding stamens of the flower in its earlier stage (at *A*), but it cannot deposit any pollen on the stigmas, which are unripe, shut together, and tucked aside out of reach. On flying to a flower in the later stage the pollen just acquired will be lodged on the prominent stigmas and thus produce the desired cross-pollination.

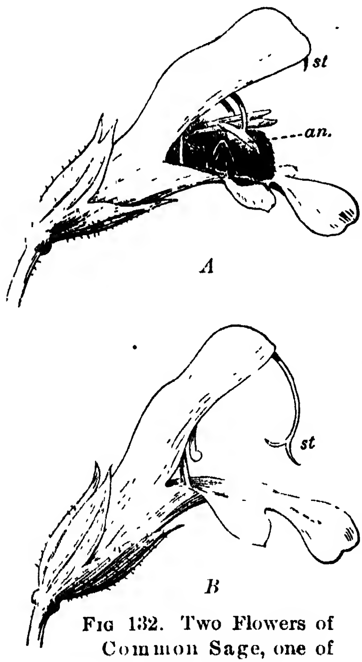


FIG 132. Two Flowers of Common Sage, one of them visited by a Bee.

210. Movements of Floral Organs to aid in Pollination. — Besides the slow movements which the stamens and pistil make in such cases as that of the *Clerodendron*, already described, the parts of the flower often admit of extensive and rather quick movements to assist the insect visitor to become dusted or smeared with pollen.

[1] *C. Thompsoniæ.*

In some flowers whose stamens perform rapid movements when an insect enters, it is easy to see how directly useful the motion of the stamens is in securing cross-pollination. The stamens of the laurel, *Kalmia*, throw little masses of pollen, with a quick jerk, against the body of the visiting insect. Barberry stamens spring up against the visitor and dust him with pollen. The common garden sage matures its anthers earlier than its stigmas. In Fig. 132, *A* the young flower is seen visited by a bee, and one anther is shown pressed closely against the side of the bee's abdomen. The stigma *st* is hidden within

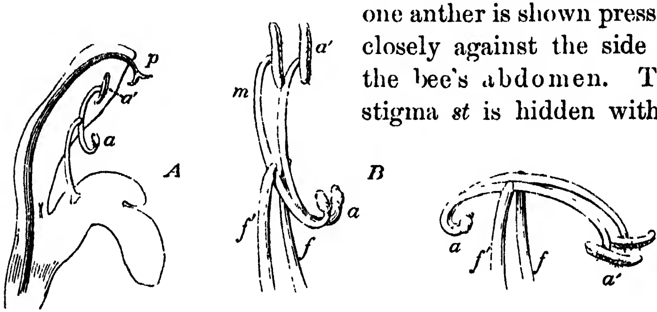
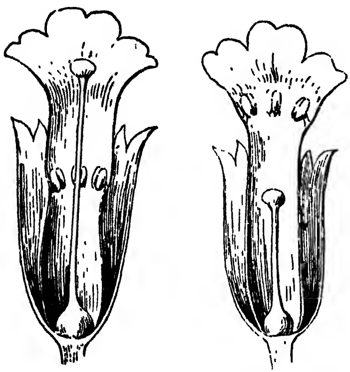


FIG. 133. Flower and Stamens of Common Sage.

A, *p*, stigma; *a*, anther; *B*, the two stamens in ordinary position; *f*, filament; *m*, connective (joining anther-cells); *a'*, anther-cells; *C*, the anthers and connectives bent into a horizontal position by an insect pushing against *a*.

the upper lip of the corolla. In *B*, an older flower, the anthers have withered and the stigma is now lowered so as to brush against the body of any bee which may enter. A little study of Fig. 133 will make clear the way in which the anthers are hinged, so that a bee striking the empty or barren anther-lobes, *a*, knocks the pollen-bearing lobes, *a'*, into a horizontal position, so that they will lie closely pressed against either side of its abdomen.

211. Flowers with Stamens and Pistils Each of Two Lengths. — The flowers of bluets, partridge-berry, the primroses, and a few other common plants secure cross-pollination by having essential organs of two forms (Fig. 134). Such flowers are said to be *dimorphous* (of two forms). In the short-styled flowers, II, the anthers are borne at the top of the corolla tube and the stigma stands about halfway up the tube. In the long-styled flowers, I, the stigma is at the top of the tube and the anthers are borne about halfway up. An insect pressing its head into the throat of the corolla of II would become dusted with pollen, which would be brushed off on the stigma of a flower like I. On leaving a long-styled flower the bee's tongue would be dusted over with pollen, some of which would necessarily be rubbed off on the stigma of the next short-styled flower that was visited. Cross-pollination is insured since all the flowers on a plant are of one kind, either long-styled or short-styled, and since the pollen is of two sorts, — each kind sterile on the stigma of any flower of similar form to that from which it came.



I II

FIG. 134. Dimorphous Flowers of the Primrose.

I, a long-styled flower; II, a short-styled one.

Trimorphous flowers, with long, medium, and short styles, are found in a species of loosestrife.[1]

[1] See Newell's *Reader in Botany*, Part II, pp. 60–63.

212. Studies in Insect Pollination. — The student cannot gather more than a very imperfect knowledge of the details of cross-pollination in flowers without actually watching some of them as they grow, and observing their insect visitors. If the latter are caught and dropped into a wide-mouthed stoppered bottle containing a bit of cotton saturated with chloroform, they will be painlessly killed, and most of them may be identified by any one who is familiar with our common insects. The insects may be observed and classified in a general way as butterflies, moths, bees, flies, wasps, and beetles, without being captured or molested.

Whether these out-of-door studies are made or not, several flowers should be carefully examined and described as regards their arrangements for attracting and utilizing insect visitors (or birds).

213. Cleistogamous Flowers. — In marked contrast with such flowers as those discussed in the preceding sections, which bid for insect visitors or expose their pollen to be blown about by the wind, are certain flowers which remain closed even during the pollination of the stigma. These flowers are called cleistogamous and of course are not cross-pollinated. Usually they occur on plants which also bear flowers adapted for cross-pollination, and in this case the closed flowers are much less conspicuous than the others, yet they produce much seed. Every one knows the ordinary flowers of the violet, but most people do not know that violets very generally, after the blossoming season (of their showy flowers) is over, produce many cleistogamous flowers, as shown in Fig. 135.

FIG 135. A Violet with Cleistogamous Flowers.

The objects which look like flower-buds are cleistogamous flowers in various stages of development. The pods are the fruit of similar flowers. The plant is represented as it appears in late July or August, after the ordinary flowers have disappeared.

CHAPTER XVIII

THE STUDY OF TYPICAL FRUITS

214. A Berry, the Tomato.[1]—Study the external form of the tomato, and sketch it, showing the persistent calyx and peduncle.

Cut a cross-section at about the middle of the tomato. Note the thickness of the epidermis (peel off a strip) and of the wall of the ovary. Note the number, size, form, and contents of the cells of the ovary. Observe the thickness and texture of the partitions between the cells. Sketch.

Note the attachments of the seeds to the placentas and the gelatinous, slippery coating of each seed.

The tomato is a typical berry, but its structure presents fewer points of interest than are found in some other fruits of the same general character, so the student will do well to spend a little more time on the examination of such fruits as the orange or the lemon.

215. A Hesperidium, the Lemon.—Procure a large lemon which is not withered, if possible one which still shows the remains of the calyx at the base of the fruit.

Note the color, general shape, surface, remains of the calyx, knob at the portion formerly occupied by the stigma. Sketch the fruit about natural size. Examine the pitted surface of the rind with the magnifying glass and sketch it. Remove the bit of stem and dried-up calyx from the base of the fruit; observe, above the calyx, the knob or *disk* on which the pistil stood. Note with the magnifying glass and count the minute whitish raised knobs at the bottom of the saucer-shaped depression left by the removal of the disk. What are they?

[1] **Fresh tomatoes, not too ripe, are to be used, or those which have been kept over from the previous summer in formalin solution. The very smallest varieties, such as are often sold for preserving, are better for study than the larger kinds.**

Make a transverse section of the lemon, not more than a fifth of the way down from the stigma end and note:

(1) The thick skin, pale yellow near the outside, white within.

(2) The more or less wedge-shaped divisions containing the juicy pulp of the fruit. These are the matured cells of the ovary; count these.

(3) The thin partition between the cells.

(4) The central column or axis of white pithy tissue.

(5) The location and attachment of any seeds that may be encountered in the section.

Make a sketch to illustrate these points, comparing it with Fig. 141.

Study the section with the magnifying glass and note the little spherical reservoirs near the outer part of the skin, which contain the oil of lemon which gives to lemon peel its characteristic smell and taste. Cut with a razor a thin slice from the surface of a lemon peel, some distance below the section, and at once examine the freshly cut surface with a magnifying glass to see the reservoirs, still containing oil, which, however, soon evaporates. On the cut surface of the pulp (in the original cross-section) note the tubes in which the juice is contained. These tubes are not cells, but their walls are built of cells. Cut a fresh section across the lemon about midway of its length and sketch it, bringing out the same points which were shown in the previous one. The fact that the number of ovary cells in the fruit corresponds with the number of minute knobs in the depression at its base is due to the fact that these knobs mark the points at which fibro-vascular bundles passed from the peduncle into the cells of the fruit, carrying the sap by which the growth of the latter was maintained.

Note the toughness and thickness of the seed-coats. Taste the kernel of the seed.

Cut a very thin slice from the surface of the skin, mount in water, and examine with a medium power of the microscope. Sketch the cellular structure shown and compare it with the sketch of the corky layer of the bark of the potato tuber.

Of what use to the fruit is a corky layer in the skin? (See Sect. 243 for further questions.)

216. A Legume, the Bean-Pod.[1] — Lay the pod flat on the table and make a sketch of it, about natural size. Label *stigma, style, ovary, calyx, peduncle.*

Make a longitudinal section of the pod at right angles to the plane in which it lay as first sketched, and make a sketch of the section, showing the partially developed seeds, the cavities in which they lie, and the solid portion of the pod between each bean and the next.

Split another pod so as to leave all the beans lying undisturbed on one-half of it, and sketch that half, showing the beans lying in their natural position and the *funiculus* or stalk by which each is attached to the *placenta;* compare Fig. 146.

Make a cross-section of another pod through one of the beans, sketch the section, and label the placenta (formed by the united edges of the pistil leaf) and the midrib of the pistil leaf.

Break off sections of the pod and determine, by observing where the most stringy portions are found, where the fibro-vascular bundles are most numerous.

Examine some ripe pods of the preceding year,[2] and notice where the *dehiscence,* or splitting open of the pods, occurs, whether down the placental edge, *ventral suture,* the other edge, *dorsal suture,* or both.

217. An Akene, the Fruit of Dock. — Hold in the forceps a ripe fruit of any of the common kinds of dock,[3] and examine with the magnifying glass. Note the three dry, veiny, membranaceous sepals by which the fruit is enclosed. On the outside of one or more of the sepals is found a tubercle or thickened appendage which looks like a little seed or grain. Cut off the tubercles from several of the fruits, put these, with some uninjured ones, to float in a pan of water, and watch their behavior for several hours. What is apparently the use of the tubercle?

[1] Any species of bean (*Phaseolus*) will answer for this study. Specimens in the condition known at the markets as "shell-beans" would be best, but these may not be obtainable in spring. Ordinary "string-beans" will do.

[2] Which may be passed round for that purpose. They should have been saved and dried the preceding autumn.

[3] *Rumex crispus, R. obtusifolius,* or *R. verticillatus.* This should have been gathered and dried the preceding summer.

Of what use are the sepals after drying up? Why do the fruits cling to the plant long after ripening?

Carefully remove the sepals and examine the fruit within them. What is its color, size, and shape? Make a sketch of it as seen with the magnifying glass. Note the three tufted stigmas attached by slender threads to the apex of the fruit. What does their tufted shape indicate?

What evidence is there that this seed-like fruit is not really a seed?

Make a cross-section of a fruit and notice whether the wall of the ovary can be seen distinct from the seed-coats. Compare the dock fruit in this respect with the fruit of the buttercup shown in Fig. 136. Such a fruit as either of these is called an *akene.*

CHAPTER XIX

THE FRUIT[1]

218. What constitutes a Fruit. — It is not easy to make a short and simple definition of what botanists mean by the term *fruit.* It has very little to do with the popular use of the word. Briefly stated, the definition may be given as follows: *The fruit consists of the matured ovary and contents, together with any intimately connected parts.* Botanically speaking, the bur of beggar's-ticks (Fig. 148), the three-cornered grain of buckwheat, or such true grains as wheat and oats, are as much fruits as is an apple or a peach.

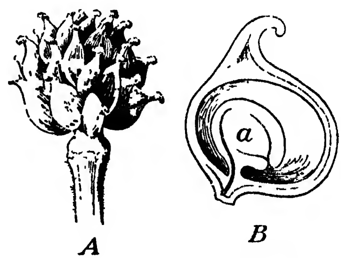


FIG. 136. Akenes of a Buttercup.
A, head of akenes; *B*, section of a single akene (magnified). *a*, seed.

219. Indehiscent and Dehiscent Fruits. — All of the fruits considered in the next three sections are *indehiscent*, that is, they remain closed after ripening. *Dehiscent* fruits when ripe open in order to discharge their seeds; three modes of dehiscence are shown in Fig. 146. The three classes which immediately follow Sect. 222 are all dehiscent.

[1] See Gray's *Structural Botany*, Chapter VII, also Kerner and Oliver's *Natural History of Plants*, Vol. II, pp. 427–438.

220. The Akene. — The one-celled and one-seeded pistils of the buttercup, strawberry, and many other flowers, ripen into a little fruit called an *akene* (Fig. 136). Such fruits, from their small size, their dry consistency, and the fact that they never open, are usually taken for seeds by those who are not botanists.

FIG. 137. Chestnuts.

221. The Grain.— Grains, such as corn, wheat, oats, barley, rice, and so on, have the interior of the ovary completely filled by the seed, and the seed-coats and the wall of the ovary are firmly united, as shown in Fig. 6..

222. The Nut. — A nut (Fig. 137) is larger than an akene, usually has a harder shell, and commonly contains a seed which springs from a single ovule of one cell of a compound ovary, which develops at the expense of all the other ovules. The chestnut-bur is a kind of involucre, and so is the acorn-cup. The name *nut* is often incorrectly applied in popular language; for example, the so-called Brazil-nut is really a large seed with a very hard testa.

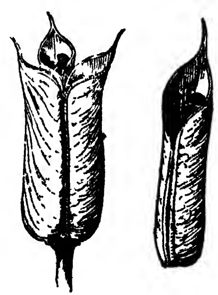


FIG. 138. Group of Follicles and a Single Follicle of the Monkshood.

223. The Follicle. — One-celled, simple pistils, like those of the columbine or the monkshood, often produce a fruit which dehisces along a single suture, usually the ventral one. Such a fruit is called a *follicle* (Fig. 138).

224. The Legume. — A legume is a one-celled pod formed by the maturing of a simple pistil, which dehisces along both of its sutures, as already seen in the case of the bean pod, and illustrated in Fig. 146.

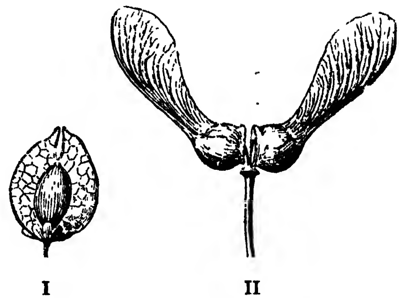


FIG. 139. Winged Fruits. I, elm; II, maple.

225. The Capsule. — The dehiscent fruit formed by the ripening of a compound pistil is called a *capsule*. Such a fruit may be one-celled, as in the linear pod of the celandine (Fig. 146), or several-celled, as in the fruit of the poppy, the morning-glory, and the jimson weed (Fig. 146).

226. Dry Fruits and Fleshy Fruits. — In all the cases discussed or described in Sects. 222–225, the wall of the ovary (and the adherent calyx when present) ripens into tissues which are somewhat hard and dry. Often, however, these parts become developed into a juicy or fleshy mass by which the seed is surrounded; hence a general division of fruits into *dry fruits* and *fleshy fruits*.

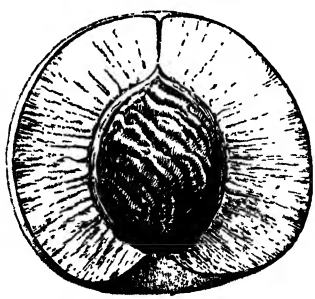


FIG. 140. Longitudinal Section of a Peach.

227. The Stone-Fruit. — In the peach, apricot, plum, and cherry, the *pericarp* or wall of the ovary, during the process of ripening, becomes converted into two kinds of

tissue, the outer portion pulpy and edible, the inner portion of almost stony hardness. In common language the hardened inner layer of the pericarp, enclosing the seed, is called the *stone* (Fig. 140); hence the name *stone-fruits.*

228. The Pome. — The fruit of the apple, pear, and quince is called a *pome.* It consists of a several-celled ovary — the seeds and the tough membrane surrounding them in the *core* — enclosed by a fleshy, edible portion which makes up the main bulk of the fruit and is formed from the much-thickened calyx, with sometimes an enlarged receptacle. In the apple and the pear much of the fruit is receptacle.

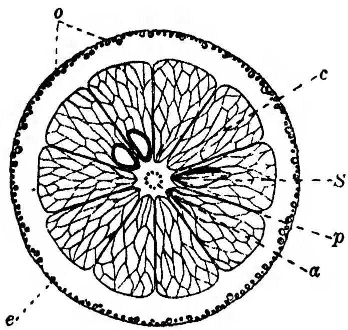


FIG. 141. Cross-Section of an Orange.

a, axis of fruit with dots showing cut-off ends of fibro-vascular bundles; *p*, partition between cells of ovary; *S*, seed; *c*, cell of ovary filled with a pulp composed of irregular tubes full of juice; *o*, oil reservoirs near outer surface of rind; *e*, corky layer of epidermis.

229. The Pepo or Gourd-Fruit. — In the squash, pumpkin, and cucumber the ripened ovary, together with the thickened adherent calyx, makes up a peculiar fruit (with a firm outer rind) known as the *pepo.* The relative bulk of enlarged calyx and of ovary in such fruits is not always the same.

How does the amount of material derived from fleshy and thickened placentæ in the squash compare with that in the watermelon?

230. The Berry. — The berry proper, such as the tomato, grape, persimmon, gooseberry, currant, and so on, consists

of a rather thin-skinned, one- to several-celled, *fleshy ovary* and its contents. In the first three cases above mentioned the calyx forms no part of the fruit, but it does in the last two, and in a great number of berries.

The gourd-fruit and the *hesperidium*, such as the orange (Fig. 141), lemon, and lime, are merely decided modifications of the berry proper.

231. Aggregate Fruits. — The raspberry (Fig. 142), blackberry, and similar fruits consist of many carpels, each

I II III

FIG. 142. I, Strawberry; II, Raspberry; III, Mulberry.

of which ripens into a part of a compound mass, which, for a time at least, clings to the receptacle. The whole is called an *aggregate fruit*.

What is the most important difference in structure between a fully ripened raspberry and a blackberry?

232. Accessory Fruits and Multiple Fruits. — Not infrequently, as in the strawberry (Fig. 142), the main bulk of the so-called fruit consists neither of the ripened ovary nor its appendages. Such a combination is called an *accessory fruit*.

Examine with a magnifying glass the surface of a small unripe strawberry, then that of a ripe one, and finally a section of a ripe

one, and decide where the separate fruits of the strawberry are found, what kind of fruits they are, and of what the main bulk of the strawberry consists.

The fruits of two or more separate flowers may blend into a single mass, which is known as a *multiple fruit.* Perhaps the best-known edible examples of this are the mulberry (Fig. 142) and the pineapple. The last-named fruit is an excellent instance of the seedless condition which not infrequently results from long-continued cultivation.

233. Summary. — The student may find it easier to retain what knowledge he has gained in regard to fruits if he copies the following synopsis of the classification of fruits, and gives an example of each kind.

- Fruits
  - composition . . .
    - simple.
    - aggregate.
    - accessory.
    - multiple.
  - texture . . . . . .
    - fleshy . . .
      - 1.
      - 2.
      - 3.
    - stone . . .
    - dry . . . .
      - 1.
      - 2.
      - 3.
      - 4.
  - mode of disseminating seed . . . . .
    - indehiscent .
      - 1.
      - 2.
      - 3.
    - dehiscent . .
      - 1.
      - 2.
      - 3.

CHAPTER XX

ECOLOGY OF FRUITS; DISPERSAL OF FRUITS AND SEEDS

234. Subjects of the Chapter. — The ecology of fruits and seeds is concerned mainly with the various means by which seeds are protected from decay or from being destroyed by animals, and the methods by which they are enabled to secure transportation and to become planted in localities suitable for their growth. The latter topic, that of seed distribution, is the one which will be discussed in this chapter.

235. Dispersal of Seeds. — Seeds are not infrequently scattered by apparatus by which the plant throws them about. More commonly, however, they depend upon other agencies, such as wind, water, or animals, to carry them. Sometimes the transportation of seeds is due to the structure of the seeds themselves, sometimes to that of the fruit in which they are enclosed; the essential point is to have transportation to a long distance made as certain as possible, to avoid overcrowding.

236. Explosive Fruits. — Some dry fruits burst open when ripe in such a way as to throw their seeds violently about. Interesting studies may be made, in the proper season, of the fruits of the common blue violet, the pansy, the wild balsam, the garden balsam, the cranes-bill, the herb Robert, the witch-hazel, the Jersey tea, and some other common plants. The capsule of the tropical

American sand-box tree bursts open when thoroughly dry with a noise like that of a pistol shot.

237. Winged or Tufted Fruits and Seeds. — The fruits of the ash, box-elder, elm, maple (Fig. 139), and many other trees are provided with an expanded membranous wing. Some seeds, as those of the catalpa and the trumpet-creeper, are similarly appendaged. The fruits of the dandelion, the thistle, the fleabane, and many other plants of the group to which these belong, and the seeds of the willow, the milkweed (Plate XI), the willow-herb, and other plants bear a tuft of hairs.

FIG. 143. Fruits of Linden, with a Bract joined to the Peduncle and forming a Wing.

The student should be able, from his own observations on the falling fruits of some of the trees and other plants above mentioned, to answer such questions as the following.

What is the use of the wing-like appendages? of the tufts of hairs?

Which set of contrivances seems to be the more successful of the two in securing this object?

What particular plant of the ones available for study seems to have attained this object most perfectly?

What is one reason why many plants with tufted fruits, such as the thistle and the dandelion, are extremely troublesome weeds?

A few simple experiments, easily devised by the student, may help him to find answers to the questions above given.[1]

[1] See Kerner and Oliver, Vol. II, pp. 833–875; also Beal's *Seed Dispersal.*

PLATE XI. Distribution of Seeds, Milkweed.

238. Tumbleweeds. — Late in the autumn, fences, particularly on prairie farms that are not carefully tilled, often serve as lodging-places for immense numbers of certain dried-up plants known as tumbleweeds. These blow about over the level surface until the first snow falls and even after that, often traveling for many miles before they come to a stop, and rattling out seeds as they go. Some of the commonest tumbleweeds are the Russian thistle (Fig. 144), the pigweed (*Amarantus albus*), the tickle-grass (Fig. 145), and a familiar pepper-grass (*Lepidium*). In order to make a

FIG. 144. Russian Thistle.

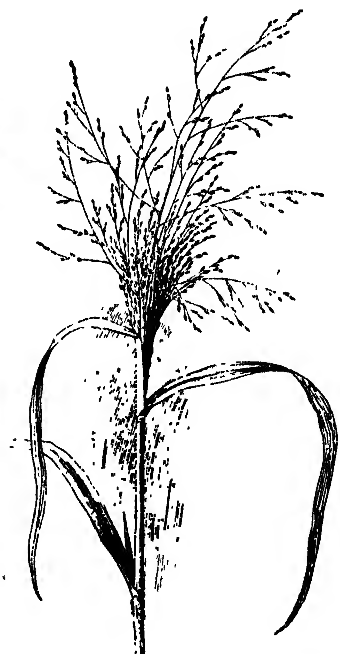


FIG. 145. Panicle of Tickle-Grass, a Common Tumbleweed.

successful tumbleweed, a plant must be pretty nearly globular in form when fully grown and dried, must be tough and light, must break off near the ground, and drop its seeds only a few at a time as it travels. A single plant of Russian thistle is sometimes as much as three feet high and six feet in diameter and carries not less than two hundred thousand seeds.

239. Many-Seeded Pods with Small Openings. — There are many fruits which act somewhat like pepper-boxes.

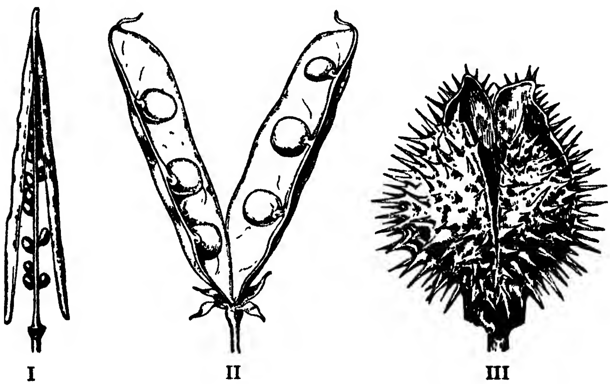


Fig. 146. Three Fruits adapted for Dispersal by the Shaking Action of the Wind.

I, celandine; II, pea; III, jimson weed (*Datura*).

The capsule of the poppy is a good instance of this kind, and the fruit of the lily, monkshood (Fig. 138), columbine, larkspur, and jimson weed (Fig. 146) acts in much the same way. Clamping the dry peduncle of any one of these ripe fruits, so as to hold it upright above the table-top, and then swinging it back and forth, will readily show its efficiency in seed dispersal.

240. Study of Transportation by Water. — Nothing less than a long series of observations by the pond-margin and the brookside will suffice to show how general and important is the work done by water in carrying the seeds of aquatics. An experiment will, however, throw some light on the subject.

EXPERIMENT XX

Adaptation for Transportation by Water. — Collect fruits of as many aquatic, semi-aquatic, or riverside and brookside species of plants as possible, place them on shallow pans of water, and notice what proportion of all the kinds studied will float. Leave them twenty-four hours or more and see whether all the kinds that floated at first are still afloat. Some desirable fruits for this experiment are aquatic grasses, rushes and sedges, polygonums, water-dock, bur-reed, arrowhead, water-plantain, pickerel-weed, alder, button-bush, water-parsnip (*Sium*), water-hemlock (*Cicuta*), water penny-wort (*Hydrocotyle*), lotus (*Nelumbo*).

241. Distances traversed by Floating Seeds. — Ocean currents furnish transportation for the longest journeys that are made by floating seeds. It is a well-known fact that cocoa-palms are among the first plants to spring up on newly formed coral islands. The nuts from which these palms grew may readily have floated a thousand miles or more without injury. On examining a cocoanut with a fibrous husk attached, just as it fell from the tree, it is easy to see how well this fruit is adapted for transportation by water. There are altogether about a hundred drifting fruits known, one (the Maldive nut) reaching a weight of from twenty to twenty-five pounds.

242. Burs. — A large class of fruits is characterized by the presence of hooks on the outer surface. These are

sometimes outgrowths from the ovary, sometimes from the calyx, sometimes from an involucre. Their office is to attach the fruit to the hair or fur of passing animals. Often, as in sticktights (Fig. 147), the hooks are comparatively weak, but in other cases, as in the cocklebur (Fig. 147), and still more in the Martynia, the fruit of

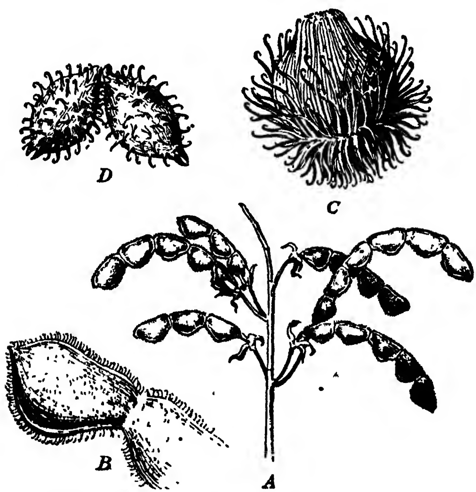


FIG. 147. Burs.

A, sticktights; *B*, sticktights, two segments (magnified); *C*, burdock; *D*, cockleburs.

which in the green condition is much used for pickles, the hooks are exceedingly strong. Cockleburs can hardly be removed from the tails of horses and cattle, into which they have become matted, without cutting out all the hairs to which they are fastened.

Why do bur-bearing plants often carry their fruit until late winter or early spring?

Plate XII. Bur Reed Fruits.

What reason can be given for the fact that the burdock, the cocklebur, the beggar's-ticks, the hound's-tongue, and many other common burs are among the most persistent of weeds?

243. Uses of Stone-Fruits and Fleshy Fruits to the Plant. — Besides the *dry fruits*, of which some of the principal kinds have been mentioned, there are many kinds of *stone-fruits and other fleshy fruits* (Sects. 227–230). Of these the great majority are eatable by man or some of the lower animals, and oftentimes the

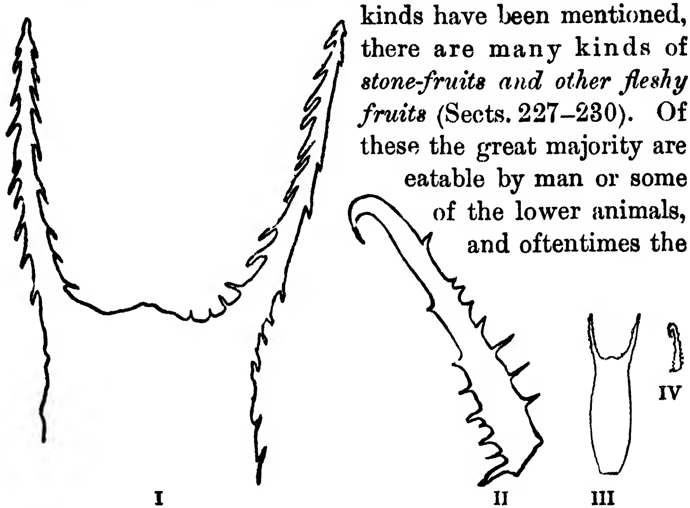


FIG. 148. Barbs and Hooks of Burs.

I, barbed points from fruit of beggar's-ticks (magnified eleven times); II, hook of cocklebur (magnified eleven times); III, beggar's-ticks fruit (natural size); IV, cocklebur hook (natural size).

amount of sugar and other food material which they contain is very considerable. It is a well-recognized principle of botany, and of zoölogy as well, that plants and animals do not make unrewarded outlays for the benefit of other species. Evidently the pulp of fruits is not to be consumed or used as food by the plant itself or (in general) by its

seeds. It is worth while, therefore, for the student to ask himself some such questions as these:[1]

(1) Why is the pulp of so many fruits eatable?

(2) Why are the seeds of many pulpy fruits bitter or otherwise unpleasantly flavored, as in the orange?

(3) Why are the seeds or the layers surrounding the seeds of many pulpy fruits too hard to be chewed, or digested, as in the date and the peach?

(4) Why are the seeds of some pulpy fruits too small to be easily chewed, and also indigestible, as in the fig and the currant?

(5) Account for the not infrequent presence of currant bushes or asparagus plants in such localities as the forks of large trees, sometimes at a height of twenty, thirty, or more feet above the ground.

Careful observation of the neighborhood of peach, plum, cherry, or apple trees at the season when the fruit is ripe and again during the following spring, and an examination into the distribution of wild apple or pear trees in pastures where they occur, will help the student who can make such observations to answer the preceding questions. So, too, would an examination of the habits of fruit-eating quadrupeds and of the crop and gizzard of fruit-eating birds during the season when the fruits upon which they feed are ripe.

244. Seed-Carrying purposely done by Animals. — In the cases referred to in the preceding sections, animals have been seen to act as unconscious or even unwilling seed-carriers. Sometimes, however, they carry off seeds with the plan of storing them for food. Ants drag away with

[1] See Kerner and Oliver's *Natural History of Plants*, Vol. II, pp. 442–450.

Plate XIII. A Bluejay burying an Acorn.

them to their nests certain seeds which have fleshy growths on their outer surfaces. Afterwards they eat these fleshy parts at their leisure, leaving the seed perfectly fit to grow, as it often does.[1]

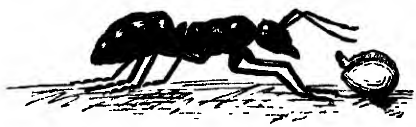


FIG. 149. Seed of Bloodroot with Caruncle or Crest, which serves as a Handle for Ants to hold on to. Ant ready to take the seed.

Squirrels and bluejays are known to carry nuts and acorns about and bury them for future use. These deposits are often forgotten and so get a chance to grow, and in this way a good deal of tree-planting is done.

[1] See Beal's *Seed Dispersal*, pp. 69, 70.

CHAPTER XXI

THE STRUGGLE FOR EXISTENCE AND THE SURVIVAL OF THE FITTEST[1]

245. Weeds. — Any flowering plant which is troublesome to the farmer or gardener is commonly known as a weed. Though such plants are annoying from their tendency to crowd out others useful to man, they are of extreme interest to the botanist on account of this very hardiness. The principal characteristics of the most successful weeds are their ability to live in a variety of soils and exposures, their rapid growth, resistance to frost, drought, and dust, their unfitness for the food of most of the larger animals, in many cases their capacity to accomplish self-pollination in default of cross-pollination, and their ability to produce many seeds and to secure their wide dispersal. Not every weed combines all of these characteristics. For instance, the velvet-leaf or butter-print,[2] common in cornfields, is very easily destroyed by frost; the pigweed and purslane are greedily eaten by pigs, and the ragweed by some horses. The horse-radish does not usually produce any seeds.

It is a curious fact that many plants which have finally proved to be noxious weeds have been purposely introduced into the country. The fuller's teasel, melilot, horse-radish,

[1] See Darwin's *Origin of Species*, Chapters III and IV.

[2] *Abutilon Avicennæ*.

wild carrot, wild parsnip, tansy, oxeye daisy, and field-garlic are only a few of the many examples of very troublesome weeds which were at first planted for use or for ornament.

246. Origin of Weeds.[1] — By far the larger proportion of our weeds are not native to this country. Some have been brought from South America and from Asia, but most of the *introduced* kinds come from Europe. The importation of various kinds of grain and of garden-seeds, mixed with seeds of European weeds, will account for the presence of many of the latter among us. Others have been brought over in the ballast of vessels. Once landed, European weeds have succeeded in establishing themselves in so many cases, because they were superior in vitality and in their power of reproduction to our native plants. This may not improbably be due to the fact that the European and western Asiatic vegetation, much of it consisting from very early times of plants growing in comparatively treeless plains, has for ages been habituated to flourish in cultivated ground and to contend with the crops which are tilled there.

247. Plant Life maintained under Difficulties. — Plants usually have to encounter many obstacles even to their bare existence. For every plant which succeeds in reaching maturity and producing a crop of spores or of seeds there are hundreds or thousands of failures, as it is easy to show by calculation. The morning-glory (*Ipomœa purpurea*) is only a moderately prolific plant, producing, in an ordinary soil, somewhat more than three thousand seeds.[2] If all these seeds were planted and grew, there would

[1] See the article *Pertinacity and Predominance of Weeds*, in *Scientific Papers of Asa Gray*, selected by C. S. Sargent, Vol. II, pp. 234–242.

[2] Rather more than three thousand two hundred by actual count and estimation.

be three thousand plants the second summer sprung from the single parent plant. Suppose each of these plants to bear as the parent did, and so on, then there would be:

9,000,000	plants the third year.
27,000,000,000	plants the fourth year.
81,000,000,000,000	plants the fifth year.
243,000,000,000,000,000	plants the sixth year.
729,000,000,000,000,000,000	plants the seventh year.

It is not difficult to see that the offspring of a single morning-glory plant would, at this rate, soon actually cover the entire surface of the earth. The fact that morning-glories do not occupy any larger amount of territory than they do must therefore depend upon the fact that the immense majority of their seeds are not allowed to grow into mature plants.

There are many plants which would yield far more surprising results in a calculation similar to that just given than are afforded by the morning-glory. For instance, a foxglove capsule contains on an average nearly 1800 seeds. A small foxglove plant bears from 140 to 200 capsules and a large one from 530 to 700. Therefore a single plant may produce over 1,250,000 seeds. A single orchid plant[1] has been shown to produce over 10,000,000 seeds.

248. Importance of Dispersal of Seeds. — It is clear that any means of securing the wide distribution of seeds is of vital importance in continuing and increasing the numbers of any kind of plant, since in this way destruction by overcrowding and starvation will be lessened.

A few of the means of transportation of seeds have been described in Sects. 235–244, but the cases are so numerous

[1] *Maxillaria;* see Darwin's *Fertilization of Orchids,* Chapter IX.

and varied that a special treatise might well be devoted to this subject alone.

249. Destruction of Plants by Unfavorable Climates. — Land-plants throughout the greater part of the earth's surface are killed in enormous numbers by excessive heat and drought, by floods, or by frost. After a very dry spring or summer the scantiness of the crops, before the era of railroads which nowadays enable food to be brought in rapidly from other regions, often produced actual famine. Wild plants are not observed so carefully as cultivated ones are, but almost every one has noticed the patches of grass, apparently dead, in pastures and the withered herbaceous plants everywhere through the fields and woods after a long drought.

Floods destroy the plants over large areas by drowning them, by sweeping them bodily away, or by covering them with sand and gravel. Frosts kill many annual plants before they have ripened their seeds, and severe and changeable winters sometimes kill perennial plants.

250. Destruction by Other Plants. — Overcrowding is one of the commonest ways in which plants get rid of their weaker neighbors. If the market-gardener sows his lettuce or his beets too thickly, few perfect plants will be produced, and the same kind of effect is brought about in nature on an immense scale. Sometimes plants are overshadowed and stunted or killed by the growth all about them of others of the same kind; sometimes it is plants of other kinds that crowd less hardy ones out of existence.

Whole tribes of parasitic plants, some comparatively large, like the dodder and the mistletoe, others microscopic, like blights and mildews, prey during their entire lives upon other plants.

251. Adaptations to meet Adverse Conditions. — Since there are so many kinds of difficulties to be met before the seed can grow into a mature plant and produce seed in its turn, and since the earth's surface offers such extreme variations as regards heat, sunlight, rainfall, and quality of soil, it is evident that there is a great opportunity offered for competition among plants. Of several plants of the same kind, growing side by side, where there is room for but one full-grown one, all may be stunted, or one may develop more rapidly than the others, starve them out, and shade them to death. Of two plants of different kinds, the hardier will crowd out the less hardy, as ragweed, pigweed, and purslane do with ordinary garden crops. Weeds like these are rapid growers, stand drought or shade well, will bear to be trampled on, and, in general, show remarkable toughness of organization.

Plants which can live under conditions that would be fatal to most others will find much less competition than the rank and file of plants are forced to encounter. Lichens growing on barren rocks are thus situated, so are mangroves (Plate XIV), and so are the fresh-water plants, somewhat like pond-scum in their structure, which are found growing in hot springs at temperatures of 140° or more.

252. Examples of Rapid Increase. — Nothing but the opposition which plants encounter from overcrowding or from the attacks of their enemies prevents any hardy kind of plant from covering all suitable portions of a whole continent, to the exclusion of most other vegetable life. New Zealand and the pampas of La Plata and Paraguay, in South America, have, during the present century, furnished wonderful examples of the spread of European species of plants over hundreds of thousands of square

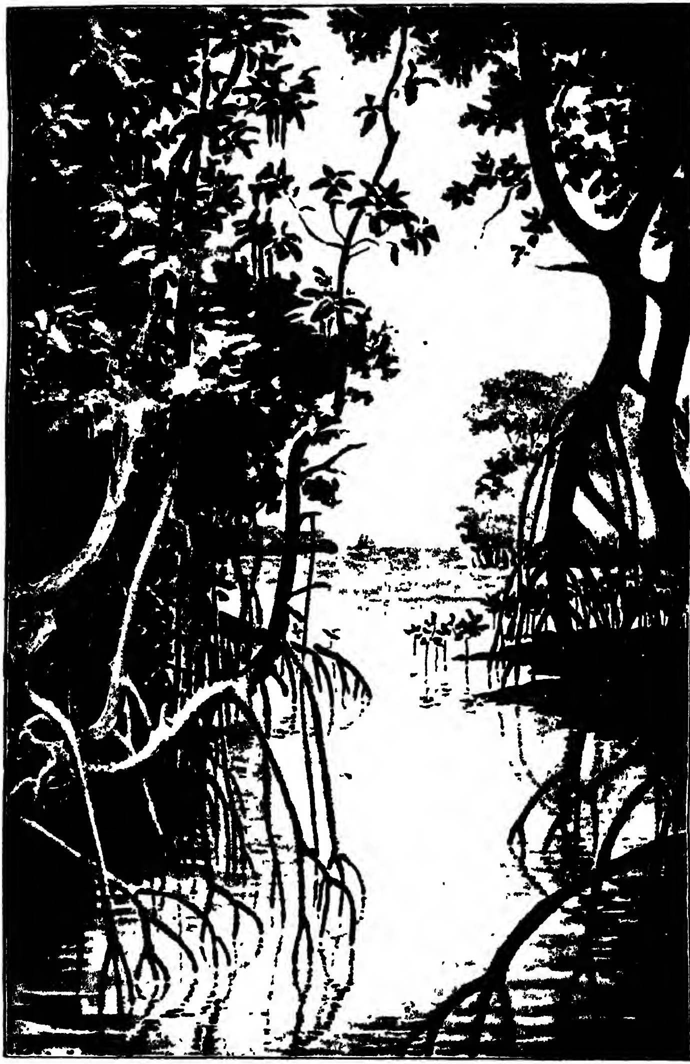


PLATE XIV. A Mangrove Swamp.

miles of territory. The newcomers were more vigorous, or in some way better adapted to get on in the world, than the native plants which they encountered, and so managed to crowd multitudes of the latter out of existence.

In our own country a noteworthy case of the kind has occurred so recently that it is of especial interest to American botanists. The so-called Russian thistle (Fig. 144), which is merely a variety of the saltwort, so common along the Atlantic coast, was first introduced into South Dakota in flaxseed brought from Russia and planted in 1873 or 1874. In twenty years from that time the plant had become one of the most formidable weeds known over an area of about twenty-five thousand square miles.

253. Importance of Adaptiveness in Plants. — It may be inferred from the preceding sections that a premium is set on all changes in structure or habits which may enable plants to resist their living enemies or to live amid partially adverse surroundings of soil or climate. It would take a volume to state, even in a very simple way, the conclusions which naturalists have drawn from this fact of a savage competition going on among living things, and it will be enough to say here that *the existing kinds of plants to a great degree owe their structure and habits to the operation of the struggle for existence*, this term including *the effort to respond to changes in the conditions by which they are surrounded.* How the struggle for existence has brought about such far-reaching results will be briefly indicated in the next section.

254. Survival of the Fittest. — When frost, drought, blights, or other agencies kill most of the plants in any portion of the country, it is often the case that many of the plants which escape do so because they can stand more

hardship than the ones which die. In this way delicate individuals are weeded out and those which are more robust survive. One shellbark hickory bears nuts whose shell is easily cracked by hogs, while another protects its seeds by a shell so hard that it is cracked only by a pretty heavy blow. In case of all such differences, there is a strong tendency to have the less eatable fruit or seed preserved and allowed to grow, while the more eatable varieties will be destroyed. The result of this kind of advantage, in any of its countless forms, is sometimes called *survival of the fittest*, and sometimes *natural selection*. The latter name means only that the outcome of the process just described, as it goes on in nature, is much the same as that of the gardener's selection, when, by picking out year by year the earliest ripening peas or certain kinds of the oddest-colored chrysanthemums, he obtains permanent new varieties. To obtain new species would be more difficult, for these are divided from each other by greater differences than those which distinguish varieties from varieties (Sects. 256, 258). It has recently been proved by Professor Hugo de Vries, of Amsterdam, Holland, that while all plants, from generation to generation, show *variations*, sometimes they show *mutations* as well. A mutation is a sudden, marked change, a sort of leap, such as the growth of pecan trees from hickory nuts or of pansies from the seed of common blue violets would be. None of the observed mutations in plants have been as conspicuous as those above suggested, but to the botanist they are quite as remarkable. Since new species produced by mutation continue to reproduce themselves, all species may, in the course of ages, have been thus produced from a few ancestral forms.

CHAPTER XXII

THE CLASSIFICATION OF PLANTS[1]

255. Natural Groups of Plants. — One does not need to be a botanist in order to recognize the fact that plants naturally fall into groups which resemble each other pretty closely, that these groups may be combined into larger ones the members of which are somewhat alike, and so on. For example, all buttercups belong to the same division or *genus*.

The marsh marigold, the hepatica, the rue anemone, and the anemone all have a family resemblance to buttercups, and the various anemones by themselves form another group like that of the buttercups.

256. Genus and Species. — Such a group as that of the buttercups is called a *genus* (plural *genera*), while the various kinds of buttercups of which it is composed are called *species*. The scientific name of a plant is that of the genus followed by that of the species. The generic name begins with a capital, the specific does not unless it is a substantive. After the name comes the abbreviation for the name of the botanist who is authority for it; thus the common elder is *Sambucus canadensis*, L., L. standing for Linnæus. Familiar examples of genera are the Violet

[1] See Warming and Potter's *Systematic Botany*, Strasburger, Noll, Schenk, and Schimper's *Text-Book of Botany*, Part II, or Engler's *Syllabus der Pflanzenfamilien* (third enlarged edition).

genus, the Rose genus, the Clover genus, the Golden-rod genus, the Oak genus. The number of species in a genus varies widely, — the Kentucky Coffee-tree genus contains only one species, while the Golden-rod genus comprises more than forty species in the northeastern United States alone.

257. Hybrids. — If the pollen of a plant of one species is placed on the stigma of a plant of the same genus but a different species, no fertilization will usually occur. In a large number of cases, however, the pistil will be fertilized and good seed be produced. This process is called *hybridization*, and any plant grown from such seed is a *hybrid*.[1] Many hybrid oaks have been found to occur in a state of nature, and hybrid forms of grapes, orchids, and other cultivated plants are produced by horticulturists at will.

258. Varieties. — Oftentimes it is desirable to describe and give names to subdivisions of species. All the cultivated kinds of apple are reckoned as belonging to one species, but it is convenient to designate such varieties as the Baldwin, the Bellflower, the Rambo, the Gravenstein, the Northern Spy, and so on.

259. Family. — Genera which resemble each other somewhat closely are classed together in one family. The particular genera mentioned in Sect. 255, together with a large number of others, combine to make up the Buttercup family. In determining the classification of plants most points of structure are important, but the characteristics of the flower and fruit outrank others because they are more constant, since they vary less rapidly than the characteristics of roots, stems, and leaves do under changed

[1] See L. H. Bailey on *Evolution of Plants*, in *Science*, March 20, 1903.

conditions of soil, climate, or other surrounding circumstances. Mere size or habit of growth has nothing to do with the matter, so the botanist finds no difficulty in recognizing the strawberry plant and the apple tree as members of the same family.

This family affords excellent illustrations of the meaning of the terms *genus*, *species*, and so on. The Rose family contains (among many others) the Pear genus, which contains the Apple species, which contains the Greening variety.

260. Grouping of Families. — Families are assembled into *classes*, and these again into larger *groups*. The details of the entire plan of classification are too complicated for any but professional botanists to master, but an outline of the scheme may be given in small space.

The entire vegetable kingdom is divided into two great divisions, the first consisting of *cryptogams* or spore-plants, the second of *phanerogams* or seed-plants. Here the relations of the various subdivisions may best be shown by a table[1] (see pages 210, 211).

[1] This is, of course, only for consultation, not to be committed to memory.

261. Table of the Classification of the Vegetable Kingdom.

Division	Group	Class	
DIVISION I CRYPTOGAMS OR SPORE-PLANTS	GROUP I MYXOTHALLOPHYTES or *plasmodial plants*	CLASS	*Myxogasteres*, Common slime-fungi.
	GROUP II THALLOPHYTES or *leafless cellular cryptogams*[1]	CLASS 1.	*Schizomycetes*, Bacteria.
		" 2.	*Schizophyceæ*, Fission-plants.
		" 3.	*Bacillariales*, Diatoms.
		" 4.	*Conjugatæ*, Desmids and pond-scums.
		" 5.	*Chlorophyceæ*, Green algæ.
		" 6.	*Phæophyceæ*, Brown algæ.
		" 7.	*Rhodophyceæ*, Red algæ.
		" 8.	*Phycomycetes*, Molds, etc.
		" 9.	*Basidiomycetes*, Mildews, rusts, and toadstools.
		" 10.	*Ascomycetes*, Yeasts, truffles, etc.
		COLLATERAL CLASS	*Lichenes*: Algæ and fungi leading a life in partnership, the combination known as a *lichen*.
	GROUP III BRYOPHYTES or *moss-like plants*	CLASS 1.	*Hepaticæ*, Liverworts.
		" 2.	*Musci*, True mosses.
	GROUP IV PTERIDOPHYTES or *fern-like plants*	CLASS 1.	*Filicales*, Ferns.
		" 2.	*Equisetales*, Scouring rushes.
		" 3.	*Lycopodiales*, Club mosses.

[1] Classes 3–7 inclusive of the thallophytes are often placed in a subgroup known as *algæ*, and 8–10 inclusive in another subgroup, *fungi*.

DIVISION II PHANEROGAMS OR SEED-PLANTS	CLASS I GYMNOSPERMS or *seed-plants with naked ovaries*, such as pines, spruces, cedars, and many other evergreen trees.	
	CLASS II ANGIOSPERMS or *seed-plants with closed ovaries*	SUBCLASS I MONOCOTYLEDONOUS PLANTS
		SUBCLASS II DICOTYLEDONOUS PLANTS

262. The Groups of Cryptogams. — The arrangement of cryptogams into the four great groups given in the preceding table is not the only way in which they could be classed. It is simply one way of dividing up the enormous number of spore-bearing plants into sections, each designated by marked characteristics of its own.

The classes given in the table do not by any means embrace all known cryptogams.

263. The Classes of Seed-Plants. — The gymnosperms are much less highly developed than other seed-plants.

The angiosperms constitute the great majority of seed-plants (or, as they have been more commonly called, flowering plants).

When people who are not botanists speak of plants they nearly always mean angiosperms. This class is more interesting to people at large than any other, not only on account of the comparatively large size and the conspicuousness of the members of many families, but also on account of the attractiveness of the flowers and fruit of many. Almost all of the book which precedes the present chapter (except Chapter V) has been occupied with seed-plants.

CHAPTER XXIII

TYPES OF CRYPTOGAMS; THALLOPHYTES

264. The Group Thallophytes. — Under this head are classed all the multitude of cryptogams which have a plant-body without true roots, stems, or leaves. Such a plant-body is called a *thallus*. In its simplest form it consists of a portion of protoplasm not enclosed in a cell-wall and without much of any physiological division of labor among its parts. Only a little less simple are such enclosed cells as that of *Pleurococcus* (Sect. 275). The most complex thallophytes, such as the higher algæ and fungi, have parts definitely set aside for absorption of food and for reproduction. The latter is sometimes accomplished by more than one process and is occasionally aided by some provision for scattering the reproductive bodies or *spores* about when they are mature.

265. Spores. — Before beginning the study of spore-plants it is well for the student to know what a spore is. *A spore is a cell which becomes free and capable of developing into a new plant.* Spores are produced in one of two ways: either *asexually*, from the protoplasm of some part of the plant (often a specialized spore-producing portion), or *sexually*, by the combination of two masses of protoplasm from two separate plants, or from different parts of the same plant.

Asexually produced spores are sometimes formed, each by the condensation of the protoplasm of a single cell, as

shown in Fig. 150, *E*. They are also formed by the contents of spore-cases breaking up into many spores (Fig. 171, *D*). Spores are sometimes produced by the spontaneous division of a mass of protoplasm into a small definite number of segments. Spores which have the power of moving (swimming) freely are known as *zoöspores* (Fig. 153, *B*).

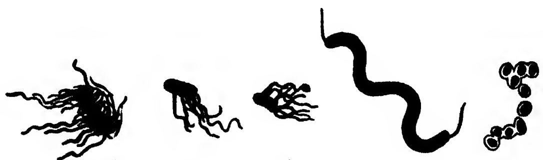


FIG. 150. Bacteria stained to show Cilia

A, *Bacillus subtilis*; *B*, *Bacillus typhi* (the bacillus of typhoid fever); *C*, *Bacillus tetani* (the bacillus which causes lockjaw); *D*, *Spirillum undula*; *E*, *Bacillus tetani* forming spores. (All five are magnified 1000 diameters.)

Sexually produced spores are formed in many ways. One of the simplest modes is that shown in Fig. 152, resulting in *zygospores*. Another method is illustrated in Fig. 156.[1]

THE STUDY OF BACTERIA

266. Occurrence. — "Bacteria may occur anywhere but not everywhere." In water, air, soil, and almost any organic substance, living or dead, some species of plant belonging to the group *Bacteria* may occur. A small bunch of hay placed in a tumbler of water will, at a suitable temperature, yield an abundant crop in a few days or hours. Raw peas or beans soaked for a week or two in water in a warm place will afford a plentiful supply.

267. Cultures. — Pure cultures of bacteria are commonly made in some preparation of gelatine in sterilized test-tubes. Boiled potatoes serve a good purpose for simple (but usually not pure) cultures.

[1] See Vine's *Student's Text-Book of Botany*, pp. 68–71.

Select a few small roundish potatoes with skins entire and boil in water for a sufficient time to cook them through. Cut them in halves with a knife well scalded or *sterilized, i.e.*, freed from all living organisms in a flame, and lay each on a saucer, with cut surface up, covering each with a glass tumbler. The tumblers and saucers should be well scalded or kept in boiling water for half an hour and used without wiping. Sterilization may be improved by baking them in an oven for an hour.

268. Inoculation. — The culture media prepared as above may now be inoculated. Uncover them only when necessary and quickly replace the cover. Scrape a little material from the teeth, tongue, kitchen sink, floor of house or schoolroom, or any other place you may desire to investigate. With the point of a knife blade or a needle sterilized in a flame, inoculate a particle of the material to be cultivated into the surface of one of the potatoes. Several cultures may be made in this way and one or more left uninoculated as checks. Another may be left uncovered in the air for half an hour. Others may be made with uncovered potatoes. Number each culture and keep a numbered record.

Keep watch of the cultures, looking at them daily or oftener. As soon as any change is noticed on the surface of a culture, make a descriptive note of it and continue to record the changes which are seen. Note the color of the areas of growth, their size, outline, elevation above the surface, and any indications of wateriness. Any growth showing peculiar colors or other characters of special interest may be inoculated into freshly prepared culture media, using any additional precautions that are practicable to guard against contamination.

269. Microscopic Examination. — Examine some of the cultures. Place a particle of the growth on a slide, dilute it with a drop of clear water, and place a cover-glass over it. Examine with the highest obtainable power of the microscope, at least $\frac{1}{6}$ in. objective. Note the forms and movements, also the sizes if practicable, of any bacteria that are found.

THE STUDY OF SPIROGYRA

270. Occurrence. — *Spirogyra*, one of the plants commonly known as pond-scum, or "frog-spit," occurs widely distributed throughout the country in ponds, springs, and clear streams. It is of a green or yellowish-green color, and in sunny weather usually floats on or near the surface of the water, buoyed up by the numerous oxygen bubbles which it sets free. It may be found flourishing in unfrozen springs, even in midwinter.

271. Examination with the Magnifying Glass.[1] — Float a little of the material in a white plate, using just water enough to cover the bottom of the latter. Study with the magnifying glass and note the green color of the threads and their great length as compared with their thickness. Are all the filaments about equal to each other in diameter?

Handle a mass of the material and describe how it feels between the fingers.

272. Examination with the Microscope. — Mount in water under a large cover-glass and examine first with a power of about 100 diameters, then with a power of 200 diameters or more. Note the structure of the filaments. Of what is each made up? Are all the units alike?

Move the slide so as to trace the whole length of several filaments, and, if the unbroken end of one can be found, study and sketch it.

Study with the higher power a single cell of one of the larger filaments and ascertain the details of structure. Try to discover, by focusing, the exact shape of the cell. How do you know that the cells are not flat? Count the bands of chlorophyll. The number of bands is an important characteristic in distinguishing one species from another.

Run in five-per-cent salt solution at one edge of the cover-glass (withdrawing water from the other edge with a bit of blotting paper). If any change in the appearance of the cell becomes evident, make a sketch to show it. What has happened to the cell-contents? Explain the cause of the change by reference to what you know of osmose.

[1] Consult Huxley's *Biology* and Spalding's *Introduction to Botany*.

On a freshly mounted slide run under the cover-glass iodine solution, a little at a time, and note its action on the nucleus. Is any starch shown to be present? If so, just how is it distributed through the cell?

273. Reproduction of Spirogyra. — The reproductive process in *Spirogyra* is of two kinds, the simplest being a process of *fission* or cell-division. The nucleus undergoes a very complicated series of transformations, which result in the division of the protoplasmic contents of a cell into two independent portions, each of which is at length surrounded by a complete cell-wall of its own. In Fig. 151 the division of the protoplasm and formation of a partition of cellulose in *Spirogyra* is well shown. The original single nucleus has already divided into two daughter nuclei. Then a wall begins as a sort of ring or diaphragm which at length completely separates the two nuclei. The original cell has now become two.

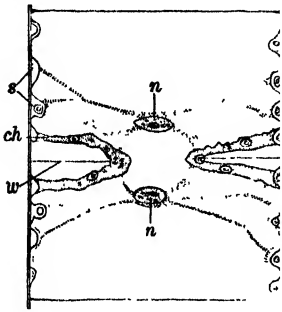
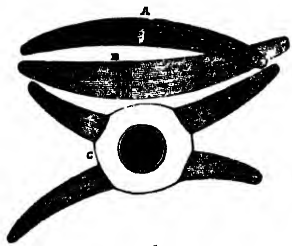


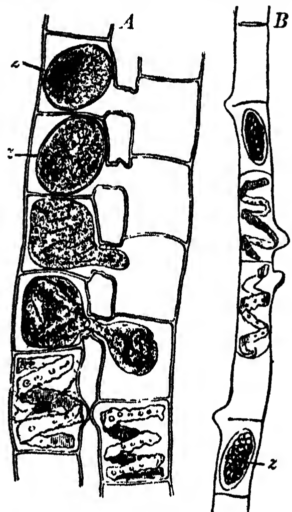
FIG. 151. Process of Cell-Multiplication in a Species of *Spirogyra*. (× 230.)

At *n*, *n* the daughter nuclei are seen on either side of the newly forming partition wall *w*. By its growth the partition pushes inward the band of chlorophyll *ch* which lines the cell-wall. Sections of this band are seen at various points *s*. Threads of protoplasm join it to the nuclei.

Another kind of reproduction, namely by *conjugation*, is found in *Spirogyra*. This process in its simplest form is found in such unicellular plants as the desmids (Fig. 152). Two cells (apparently precisely alike) come in contact, undergo a thinning-down or absorptive process in the cell-walls at the point of contact, and finally blend their protoplasmic cell-contents, as shown in the figure, to form a mass known as a *spore*, or more accurately a *zygospore*, from which, after a period of rest, a new individual develops. In *Spirogyra* each cell of the filament appears to be an individual and can conjugate like the one-celled desmids. It is not easy to watch the process, since the spore-formation takes place at night. It is possible, however, to retard the occurrence of conjugation by leaving the *Spirogyra* filaments in very cold water over night, and in this way the successive steps of the conjugating

process may be studied by daylight. In such ways the series of phenomena shown in Fig. 152 has been accurately followed. If the student cannot follow these operations under the microscope, he may, at least, by looking over the yellower portions of a mass of *Spirogyra*, find threads containing fully formed zygospores, like those shown in *B*, Fig. 152.





I II

FIG. 152. Conjugation of Cells of Green Algæ. (Much magnified.)

I, Conjugation of Desmids. *A*, a single plant in its ordinary condition; *B*, empty cell-wall of another individual; *C*, conjugation of two individuals to form a spore by union of their cell-contents.

II, Conjugation of *Spirogyra*. *A*, two filaments of *Spirogyra* side by side, with the contents of adjacent cells uniting to form spores, *z*. At the bottom of the figure the process is shown as beginning, at the top as completed, and the cells of one filament emptied; *B*, a single filament of another kind of *Spirogyra*, containing two spores, one lettered *z*. (*A* magnified 240 diameters; *B*, 150 diameters.)

THE STUDY OF PLEUROCOCCUS

274. Occurrence. — *Pleurococcus* may be found on old fences, roofs, and many similar places, particularly on the bark of the north side of trees. The individual plants cannot be detected by the naked eye, but when grouped in masses they form a powdery green covering over indefinite areas of bark. Plenty are seen where it is moist.

275. Microscopical Examination of Pleurococcus. — Scrape a minute quantity of *Pleurococcus* from a specimen on bark, place it in a drop of water on a slide, distributing it slightly in the water, lay on it a cover-glass, and examine with a power of 200 or more diameters. Sketch with the *camera lucida* one of the largest cells, some of intermediate size, and one of the smallest, beside several divisions of the stage micrometer.

Note the clearly defined cell-wall of cellulose, enclosing the protoplasmic contents, usually green throughout. Do any cells show a nucleus like that in Fig. 153?

Test the cells with iodine solution for starch.

Note that in reproduction the cell-contents in many individuals has divided into two parts, which become separated from each other by a cellulose partition. Each of these again divides, and the process continues until thirty-two or more cells may be found in one mass, or they may fall apart at an earlier stage.

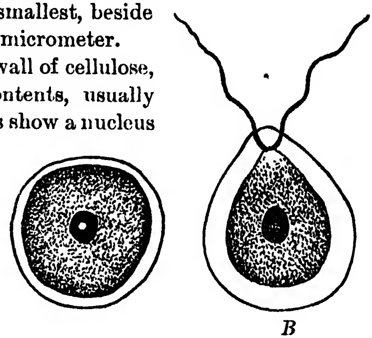


Fig. 153. Two Cells of *Protococcus*. (Greatly magnified.)

A, a spherical cell of the still form; *B*, a motile cell with its protoplasm enclosed in a loose cell-wall and provided with two cilia.

276. Nutrition of Pleurococcus.—*Pleurococcus* can flourish only with an abundance of light and moisture. In daylight it can absorb carbon dioxide and fix carbon (giving off the oxygen at the same time in the form of bubbles) and can assimilate mineral substances. It is a capital example of an individual cell capable of independent existence.

277. Motile Forms. — No motile form is known in *Pleurococcus*. *Hæmatoccus*, often known as *Protococcus* (Fig. 153), is a better object for study but more difficult to collect than *Pleurococcus*. It may sometimes be found in water of stagnant pools, particularly those which contain the drainage of barnyards or manure-heaps, in mud at the bottom of eaves-troughs, in barrels containing rain-water, or in water standing in cavities in logs or stumps. Its presence is indicated by a greenish or sometimes by a reddish color. It is sometimes found in an actively swimming condition, in which case each cell is called a *zoöspore*.

THE STUDY OF ROCKWEED[1]

278. Occurrence.—The common rockweed is abundant everywhere on rocks, between high and low tide, on the New England coast and southward.

279. The Frond. — A plant of rockweed consists mostly of a growth which is somewhat leaf-like, but, in fact, stem and leaf are not separately developed, and the growth is therefore called a *thallus.* This combined stem and leaf has many flat leathery branches which are buoyed up in the water by air-bladders. Cut one of the bladders open and note its form and appearance. Note whether they occur singly or how grouped. Note the prominent midrib running throughout the middle of each branch. Examine the swollen tips of some of the branches and note their peculiarities. Sketch a portion of a frond to show the characteristics so far noted.

FIG. 154. Part of Thallus of a Rockweed (*Fucus platycarpus*). (Natural size.)

The two uppermost branchlets are fertile.

280. Reproduction. —Cut across through the middle of one of the swollen fruiting tips. Note the fruiting papillæ (*conceptacles*) as they appear in this section, and make a simple sketch to show their position.

Select some plants with brighter-colored tips and some less bright, if any difference can be detected. After making the microscopic examination which follows, note what correspondence of structure with color has been observed. Cut very thin sections through fruiting tips from different plants, keeping those from each

[1] *Fucus vesiculosus* is the most available species. Others may be substituted.

plant separate. Be sure that some of the cuts pass through the conceptacle as near the middle as possible.

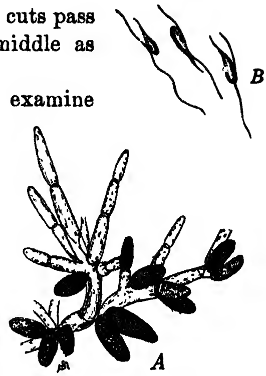


FIG. 155. Rockweed (*Fucus*).

A, antheridia borne on branching hairs (× 160); *B*, antherozoids from same (× 330).

With a power of about 60 diameters examine sections from different fronds, searching for one kind containing rather large egg-shaped cells and another containing bundles of numerous smaller sac-shaped cells. With a power of 200 diameters study the details of the sections. Note the character of the cells forming the surface of the frond, those of the inner structure, and those limiting the cavity of the conceptacle. In a conceptacle cut through the middle note the form of the orifice. Examine the slender hairs or filaments (*paraphyses*) which, arising at right angles, line the walls of the conceptacle.

281. Oögonia and Antheridia. — In conceptacles containing egg-shaped cells (*oögonia*) note the form, mode of attachment (sessile or stalked), and different stages of development. At maturity the contents are divided, forming eight oöspheres; but not all can be seen at once, some being beneath the others.

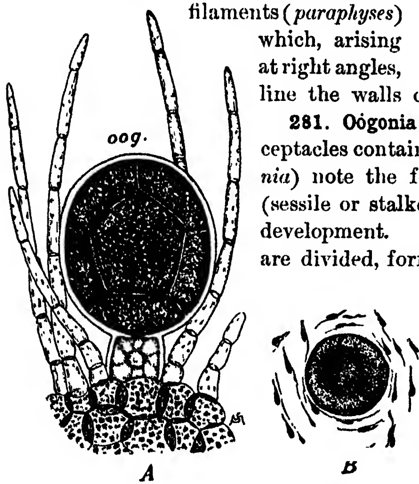


FIG. 156. Rockweed (*Fucus*).

A, oögonium, its contents dividing into eight oöspheres (× 160); *B*, an oösphere, escaped, surrounded by antherozoids (× 160).

In conceptacles of the other kind examine the numerous small sac-shaped cells (*antheridia*). At maturity the contents of each divide to form numerous very minute motile *antherozoids*, each with two delicate hairs

or cilia. Dissect, by picking and by friction under a cover-glass, a bunch of antheridia and note the branching filaments upon which they are borne.

Make drawings to illustrate the various points of structure.

282. Number of Antherozoids required for Fertilization. — The bulk of an oösphere has been estimated to be equal to that of thirty thousand to sixty thousand antherozoids, but apparently an oösphere may be fertilized by only one antherozoid. Yet a large number swarm around each oösphere after both have escaped from the conceptacles, and often their movements are so active as to cause the rotation of the oösphere. The process of fertilization may be discerned in fresh material by squeezing oöspheres and antherozoids from their respective conceptacles into a drop of water on a slide. In some species, as *Fucus platycarpus* (Fig. 154), antheridia and oögonia are found in the same conceptacle.

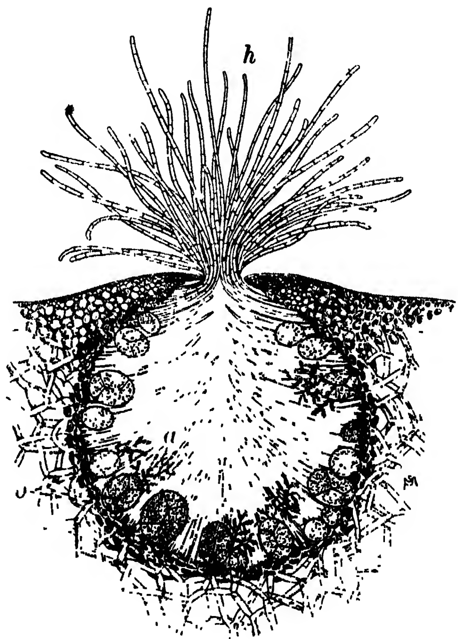


FIG. 157. Transverse Section of Conceptacle of a Rockweed (*Fucus platycarpus*). (× about 35.)

h, hairs; *a*, antheridia; *o*, oögonia.

283. Algæ. — *Pleurococcus*, *Spirogyra*, and *Fucus*, which we have just studied, are but a few types of several families

of plants which together make the great group called *Algæ.* Something of its importance in nature is indicated by the following facts. The number of known species is about 12,000. In size, the individuals in various species range from a single cell of microscopic dimensions, as in *Pleurococcus*, to the giant kelp of California which reaches a length of more than 1000 feet. The form ranges from a simple spherical cell as in *Pleurococcus* to an extensive, branching cell in other groups, and to specialized organs in the form of root, stem, leaf, air-bladder, and fruiting organs in *Sargassum*, which is an ally of *Fucus.*

The algæ illustrate a series of modes of propagation from simple division to the union of two similar masses of protoplasm to form a spore in *Spirogyra* and the direct fertilization of a germ-cell by motile antherozoids in *Fucus.*

The algæ fall into five natural groups based primarily on the mode of fruiting.

THE STUDY OF BLACK MOLD

(*RHIZOPUS NIGRICANS*)

284. Occurrence. — This mold may be found in abundance on decaying fruits, such as tomatoes, apples, peaches, grapes, and cherries, or on decaying sweet potatoes or squashes. For class study it may most conveniently be obtained by putting pieces of wet bread on plates for a few days under bell-jars and leaving in a warm place until patches of the mold begin to appear.

285. Examination with the Magnifying Glass. — Study some of the larger and more mature patches and some of the smaller ones. Note:

(*a*) The slender, thread-like network with which the surface of the bread is covered. The threads are known as *hyphæ*, the entire network is called the *mycelium.*

(*b*) The delicate threads which rise at intervals from the mycelium and are terminated by small globular objects These little spheres are spore-cases. Compare some of the spore-cases with each other and notice what change of color marks their coming to maturity.

286. Examination with the Microscope. — Sketch a portion of the untouched surface of the mold as seen (opaque) with a two-inch objective, and then compare with Fig. 158.

Wet a bit of the mold, first with alcohol and then with water. Examine in water with the half-inch objective, and sketch a little of

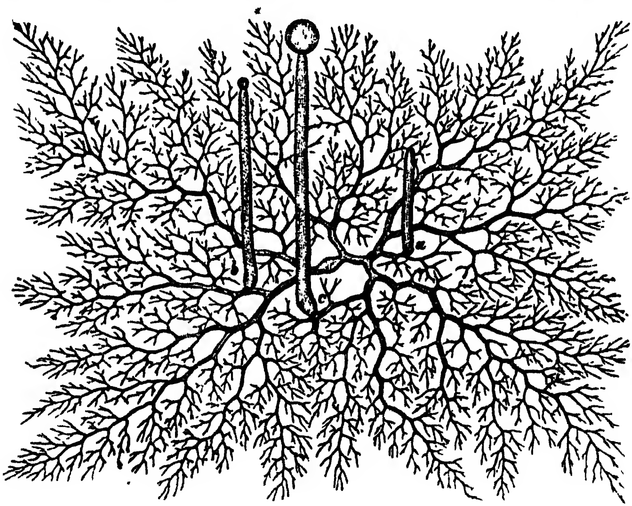


Fig. 158. Unicellular Mycelium of a Mold (*Mucor Mucedo*), sprung from a Single Spore.

a, *b*, and *c*, branches for the production of spore-cases, showing various stages of maturity. (Considerably magnified.)

the mycelium, some of the spore-cases, and the thread-like stalks on which they are borne. Are these stalks and the mycelium filaments solid or tubular? Are they one-celled or several-celled?

Mount some of the mature spore-cases in water, examine them with the highest obtainable power, and sketch the escaping spores.

Sow some of these spores on the surface of "hay-tea," made by boiling a handful of hay in just water enough to cover it and then straining through cloth or filtering through a paper filter. After from three to six hours examine a drop from the surface of the liquid with a medium power of the microscope (half-inch objective) to see how the development of hyphæ from the spores begins. Sketch.

After about twenty-four hours examine another portion of the mold from the surface of the liquid and study the more fully developed mycelium. Sketch.

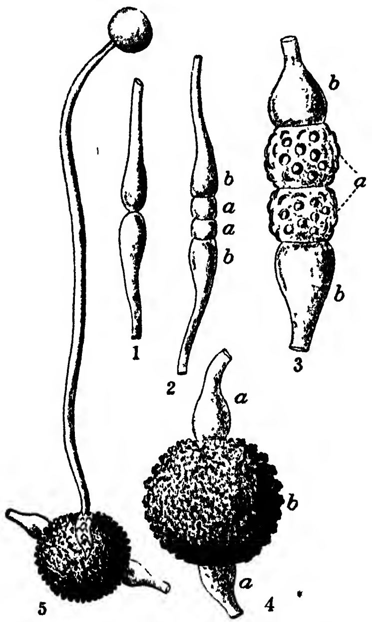


Fig. 159. Formation of Zygospores in a Mold (*Mucor Mucedo*).

1, threads in contact previous to conjugation; 2, cutting off of the conjugating cells *a* from the threads *b*; 3, a later stage of the process; 4, ripe zygospore; 5, germination of a zygospore and formation of a spore-case. (1–4 magnified 225 diameters; 5 magnified about 60 diameters.)

287. Zygospores.—Besides the spores just studied, *zygospores* are formed by conjugation of the hyphæ of the black molds. It is not very easy to find these in process of formation, but the student may be able to gather from Fig. 159 the nature of the process by which they are formed, — a process which cannot fail to remind him of the conjugation of pond-scum.

THE STUDY OF WHEAT RUST

(*PUCCINIA GRAMINIS*)

288. Occurrence. — Wheat rust is common on cultivated wheat and other grains, and also on many wild and cultivated forage grasses. In fact, this or similar rusts occur on a very large number

of grasses, and many species of such rusts are recognized. A rust may have one, two, or three kinds of spores, and when three occur one is known as the *cluster-cup stage* and the others as *red rust* and *black rust*, according to the usual approximate color of the spores.

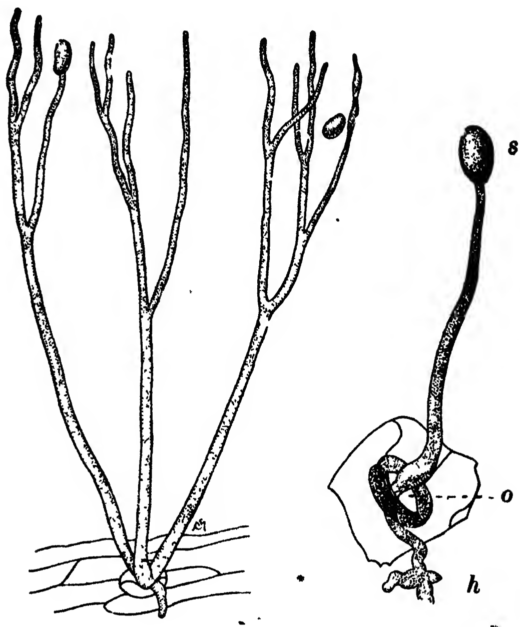


FIG. 160. Spore-Formation in Potato-Blight (*Phytophthora infestans*).

A, a well-developed group of stalks, proceeding from a mass of mycelium inside the leaf and escaping through a stoma; *B*, a young, unbranched stalk. *h*, hyphæ of mycelium; *o*, stoma; *s*, spore. (Both figures greatly magnified, *B* more than *A*.)

The rust called *Puccinia graminis*, growing on wheat, has its cluster-cup stage on the leaves of barberry in June. The spores from the cluster-cups are carried by the wind to the wheat, where they germinate and in a few days produce the red rust. A little later the black

spores appear, produced from the same mycelium. This growth is chiefly upon the stems and sheaths.

289. Cluster-Cup Stage. — Note with the naked eye and with a magnifying glass the appearance of the cluster-cups upon the barberry leaf. Fresh specimens should be used if available. Note whether the leaf is changed in form or color in any part occupied by the fungus. Note the number of cups in a cluster, the position on the leaf (which surface?), the form and size, especially the height. Are they straight or curved? Describe the margin of the cup, the color without, and the color of the contents.

With a power of 200 diameters or more examine some of the cells composing the cup and note the form, color, and nature of the surface. Draw. With the point of a needle or knife pick out a bit of the contents of the cup and examine as above. Note the characters as before and compare in detail with the cells of the cup. The cells within the cup are the spores. Can you tell how they are attached?

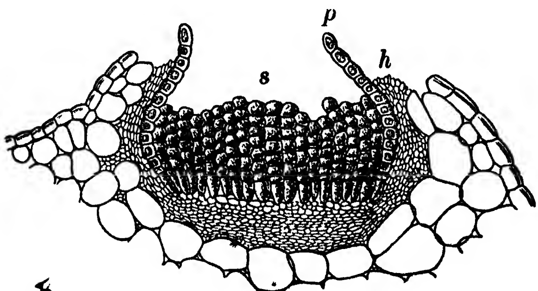


FIG. 161. — Cluster-Cup of Anemone Rust (*Puccinia fusca*). (× 120.) *s*, chains of spores; *p*, the covering or peridium of the cup; *h*, hyphæ.

A thin section through the cup will show the mode of attachment and the relation of the spores to the cup.

290. Examination of Red and Black Rust. — Under the magnifying glass examine the eruptions of spores (*sori*) on the wheat plant, some of red spores and some of black spores. The red spores are faded in dried specimens. Note the approximate size and shape and any other peculiarities. Prepare slides of each kind of spores and see if

both can be found in one sorus. The spores may be taken from the host-plant on the point of a knife by picking rather deeply down into the sorus. Place the small quantity of spores so obtained in a drop of water on a slide, spread with dissecting needles, and cover. Examine under a power of 200 or more diameters.

The red spores (*uredospores*) have each a stalk from which they easily fall. They may be seen attached to their stalks if properly prepared cross-sections through the sorus are available, especially if the material is fresh. Examine the spores and note the shape, color, and surface. If the spores are shrunken, a drop of potash solution will restore the natural plumpness. Draw. Spore-measurements are important in determining species. The *uredospores* of *Puccinia graminis* may be distinguished from those of other species common on grasses by the greater proportionate length.

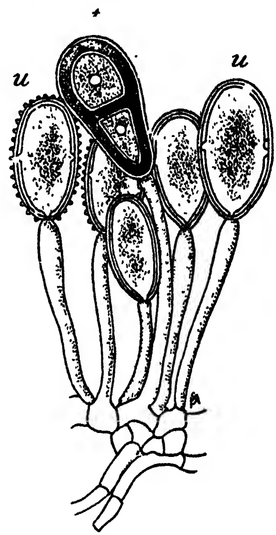


FIG. 162. A Group of Spores of Wheat Rust (*Puccinia graminis*). (× about 440.)
u, *u*, uredospores; *t*, teleutospore.

The structure of the black spores (*teleutospores*) can be made out without difficulty. Some should be found attached at the base. Note the parts and the differences in color in different portions. Make careful drawings to show shape and structure of both kinds of spores.

Boil a portion of a rust-injured plant in potash solution, pick it to pieces on a slide under the magnifier or dissecting microscope, use a cover-glass, and examine the preparation for mycelium, using a high power.

291. Cultivation on a Host-Plant. — If practicable, find some wheat or grass which has remained over winter with the black rust upon it. Tie a bunch of this to a barberry bush while the leaves are young or unexpanded. When the time arrives for the appearance of the

cluster-cups, note whether they are any more abundant on this bush than on others. Are you sure that the rust you have is the one to which the barberry cluster-cups belong?

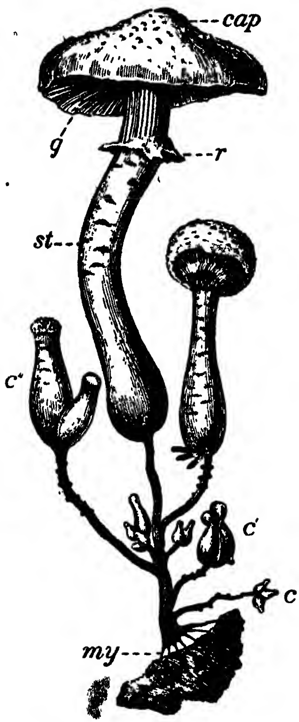


Fig. 163. A Mushroom (*Agaricus melleus*).

my, mycelium; *c*, *c'*, *c''*, young "buttons"; *st*, stipe or stalk; *r*, ring; *g*, gills.

THE STUDY OF AGARICUS

292. Occurrence. — The common mushroom, *Agaricus campestris*, grows in open fields and pastures in the United States and Europe. It is the mushroom most extensively cultivated for market, and if not found in the field it may be raised from "spawn" (*mycelium*), put up in the shape of bricks, and sold by seedsmen in the large cities. Those who make a specialty of selling it furnish directions for culture free. A moderately warm cellar or basement makes an excellent winter garden for mushrooms.

293. Structure of Mycelium. — Examine some of the spawn, or mycelium, with the magnifying glass and the low power of the microscope, and with a power of 200 diameters or more examine the individual hyphæ which compose it. Are the hyphæ united in cord-like strands or otherwise, or are they entirely separate? Look for cross-partitions in the hyphæ. Is there any peculiar structure to be found at these places? Are the cross-partitions near together or widely separated?

294. The Spore-Plant. — Search for indications of fruiting, and note the appearance of the "button mushrooms" in all available stages. Draw. See if at any stage up to maturity an outer envelope

PLATE XV. Oyster Fungus on a Linden Tree.

of tissue (*volva*) can be found enclosing the entire fruiting body. If such be present, what becomes of it at maturity? If material is available, compare the species of *Amanita* (poisonous) in regard to this.

Examine specimens in which the cap is expanding and see if there is another tissue forming a *veil* covering the under surface of the cap. If such be present, how is it attached and what becomes of it?

Take a fresh, well-expanded mushroom or toadstool. Remove the stalk or *stipe* close under the cap or *pileus*, and lay the latter, gills down, on a piece of paper. Let it remain undisturbed for a few hours, or over night, so that the spores may fall upon the paper. Note carefully their color, also the form in which they are arranged on the paper. What determines this form? Examine some of the spores under the highest available power of the microscope. Measure and draw.

Describe the stipe. Is it a hollow tube or solid? Does it taper? Note length, diameter, color.

Describe the cap or pileus in regard to diameter, thickness, nature and color of the upper surface, also color below.

Examine the plates or *gills*, which compose the under portion of the pileus. Cut a complete pileus and stipe through the center, and draw an outline to show the shape, noting particularly how the gills are attached. What is the color of the gills?

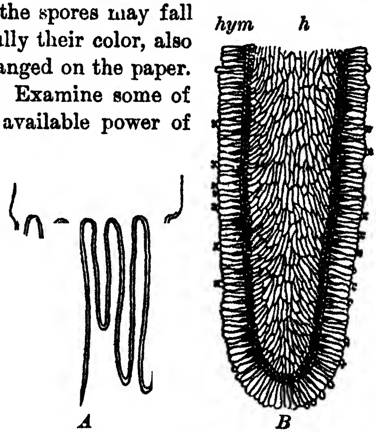


FIG. 124. Portions of Gills of a Fungus (*Agaricus*).

A, slightly magnified; *B*, one of the parts of *A*, more magnified. *hym*, hymenium; *h*, central layer.

295. Origin of Spores. — Make a cross-section of one of the gills, and with a magnifying power of about 200 diameters examine the fruiting cells (*basidia*) which project at right angles to the gill and bear the spores. At how many points (*sterigmata*) on each basidium are spores attached? Draw a basidium, preferably one from which the spores have not yet fallen.

THE STUDY OF YEAST

(*SACCHAROMYCES CEREVISIÆ*)

296. Growth of Yeast in Dilute Syrup. — Mix about an eighth of a cake of compressed yeast with about a teaspoonful of water and stir until a smooth, thin mixture is formed. Add this to about half a pint of water in which a tablespoonful of molasses has been dissolved. Place this mixture in a wide-mouthed bottle which holds one or one and a half pints, stopper *very loosely*,[1] and set aside for from twelve to twenty-four hours in a place in which the temperature will be from 70 to 90 degrees. Watch the liquid meantime and note:

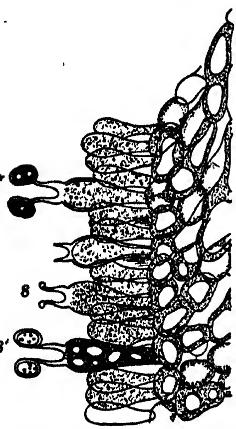


FIG. 165. Part of the Preceding Figure. (× about 300.)

C, layer of cells immediately under the hymenium. *s*, *s′*, *s″*, three successive stages in growth of spores.

(*a*) The rise of bubbles of gas in the liquid.

(*b*) The increasing muddiness of the liquid, a considerable sediment usually collecting at the end of the time mentioned.

(*c*) The effect of cooling off the contents of the bottle by immersing it in broken ice if convenient, or, if this is not practicable, by standing it for half an hour in a pail of the coldest water obtainable, or leaving it for an hour in a refrigerator, afterwards warming the liquid again.

(*d*) The effect of shutting out light from the contents of the bottle by covering it with a tight box or large tin can.

(*e*) The result of filling a test-tube or a very small bottle with some of the syrup-and-yeast mixture, from which gas-bubbles are freely rising, and immersing the small bottle up to the top of the neck for fifteen minutes in boiling water. Allow this bottle to

[1] If the cork is crowded into the neck with any considerable force, pressure of gas and an explosion may result.

stand in a warm place for some hours after the exposure to hot water. What has happened to the yeast-plants?

(*f*) The behavior of a lighted match lowered into the air space above the liquid in the large bottle, after the latter has been standing undisturbed in a warm place for an hour or more.

(*g*) The smell of the liquid and its taste.

297. Microscopical Examination of the Sediment.[1] — Using a very slender glass tube as a pipette, take up a drop or two of the liquid and the upper layer of the sediment and place on a glass slide, cover with a very thin cover-glass, and examine with the highest power that the microscope affords.

Note:

(*a*) The general shape of the cells.

(*b*) Their granular contents.

(*c*) The clear spot or vacuole seen in many of the cells.

Sketch some of the groups and compare the sketches with Fig. 166.

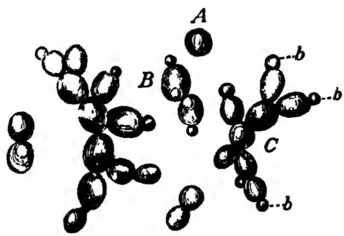


FIG. 166. Yeast (*Saccharomyces ellipsoideus*) budding actively.

A, a single cell; *B*, group of two budding cells; *C*, a large group. *b*, buds.

Run in a little iodine solution under one edge of the cover-glass, at the same time touching a bit of blotting paper to the opposite edge, and notice the color of the stained cells. Do they contain starch?

Place some vigorously growing yeast on a slide under a cover-glass and run in a little eosin solution or magenta solution. Note the proportion of cells which stain at first and the time required for others to stain. Repeat with yeast which has been placed in a slender test-tube and held for two or three minutes in a cup of boiling water.

With a very small cover-glass, not more than three-eighths of an inch in diameter, it may be found possible, by laying a few bits of blotting paper or cardboard on the cover-glass and pressing it against the slide, to burst some of the stained cells and thus show their thin, colorless *cell-walls* and their semi-fluid contents, *protoplasm*, nearly colorless in its natural condition but now stained by the iodine.

[1] See Huxley and Martin's *Biology*, under *Torula*.

EXPERIMENT XXI

Can Yeast grow in Pure Water or in Pure Syrup? — Put a bit of compressed yeast of about the size of a grain of wheat in about four fluid ounces of distilled water, and another bit of about the same size in four fluid ounces of 10 per cent solution of rock candy in distilled water; place both preparations in a warm place, allow to remain for twenty-four hours, and examine for evidence of the growth of the yeast added to each.

298. Size, Form, and Structure of the Yeast-Cell. — The student has discovered by his own observations with the microscope that the yeast-cell is a very minute object, — much smaller than most of the vegetable cells which he has hitherto examined. The average diameter of a yeast-cell is about $\frac{1}{3000}$ of an inch, but they vary greatly both ways from the average size.

The general form of most of the cells of ordinary yeast is somewhat egg-shaped. The structure is extremely simple, consisting of a thin cell-wall, which is wholly destitute of markings, and a more or less granular semi-fluid protoplasm, sometimes containing a portion of clearer liquid, the *vacuole*, well shown in the larger cells of Fig. 166.[1]

299. Substances which compose the Yeast-Cell. — The cell-wall is composed mostly of *cellulose;* the protoplasm consists largely of water, together with considerable portions of a proteid substance,[2] some fat, and very minute portions of *sulphur*, *phosphorus*, *potash*, *magnesia*, and *lime*. It is destitute of chlorophyll, as would be inferred from its lack of green color, and contains no starch.

[1] This is not the ordinary commercial yeast.

[2] It may be found troublesome to apply tests to the yeast-cell on the slide, under the cover-glass. Testing a yeast cake is not of much value, unless it may be assumed that compressed yeast contains little foreign matter and consists mostly of yeast-cells. Still the test is worth making. Millon's reagent does not work well, but the red or maroon color which constitutes a good test for proteids is readily obtained by mixing a teaspoonful of granulated sugar with enough strong sulphuric acid to barely moisten the sugar throughout, and then, as quickly as possible, mixing a bit of yeast cake with the acid and sugar. A comparative experiment may be made at the same time with some other familiar proteid substance, *e.g.*, wheat-germ meal.

300. Food of the Yeast-Cell; Fermentation. — The diluted molasses in which the yeast was grown in Experiment XXI contained all the mineral substances mentioned in Sect. 299 together with sugar, proteid materials, and water. The addition of a little nitrate of ammonium would probably have aided the growth of the yeast in this experiment by supplying more abundantly the elements out of which the yeast constructs its proteid cell-contents. A great deal of sugar disappears during the growth of the yeast.[1] Most of the sugar destroyed is changed into carbon dioxide (which the student saw rising through the liquid in bubbles) and alcohol, which can be separated from the liquid by simple means. The process of breaking up weak syrup into carbon dioxide and alcohol by aid of yeast is one kind of *fermentation;* it is of great practical importance in bread-making and in the manufacture of alcohol. Since grape juice, sweet cider, molasses and water, and similar liquids, when merely exposed to the air, soon begin to ferment and are then found to contain growing yeast, it is concluded that dried yeast-cells in the form of dust must be everywhere present in ordinary air.

301. Yeast a Plant; a Saprophyte. — The yeast-cell is known to be a plant, and not an animal, from the fact of its producing a coating of cellulose around its protoplasmic contents and from the fact that it can produce proteids out of substances from which animals could not produce them.[2]

On the other hand, yeast cannot live wholly on carbon dioxide, nitrates, water, and other mineral substances, as ordinary green plants can. It gives off no oxygen, but only carbonic acid gas, and is therefore to be classed with the *saprophytes*, like the Indian pipe, among flowering plants (Sect. 164).

302. Multiplication of Yeast. — It is worth while to notice the fact that yeast is one of the few cryptogams which have for ages been largely cultivated for economic purposes. Very recently yeast producing has become a definite art, and the cakes of compressed yeast so commonly sold afford only one instance of the success that has been attained in this process. While yeast-cells are under favorable

[1] The sugar contained in molasses is partly cane sugar and partly grape sugar. Only the latter is detected by the addition of Fehling's solution. Both kinds are destroyed during the process of fermentation.

[2] For example, tartrate of ammonia.

conditions for growth they multiply with very great rapidity. Little protrusions are formed at some portion of the cell-wall, as the thumb of a mitten might be formed by a gradual outgrowth from the main portion. Soon a partition of cellulose is constructed, which shuts off the newly formed outgrowth, making it into a separate cell, and this in turn may give rise to others, while meantime the original cell may have thrown out other offshoots. The whole process is called *reproduction by budding.* It is often possible to trace at a glance the history of a group of cells, the oldest and largest cell being somewhere near the middle of the group and the youngest and smallest members being situated around the outside. Less frequently the mode of reproduction is by means of *spores*, new cells (usually four in number) formed inside one of the older cells (*ascus*). At length the old cell-wall bursts and the spores are set free to begin an independent existence of their own.

In examining the yeast-cell the student has been making the acquaintance of plant life reduced almost to its lowest terms. The very simplest plants consist of a speck of jelly-like protoplasm. Yeast is more complex from the fact that its protoplasm is surrounded by an envelope of cellulose, — the cell-wall.

303. Fungi. — The yeasts, molds, rusts, mildews, and mushrooms represent an immense group of plants of which about forty-five thousand species are now known in the world. They range from the very simple to quite complex forms, growing as saprophytes or parasites under a great variety of conditions. Their structure and life history are so varied as to constitute a long series of divisions and subdivisions.[1] Chlorophyll is absent from fungi, and they are destitute of starch, but produce a kind of cellulose which appears to differ chemically from that of other plants. Unable to build up their tissues from carbonic acid gas, water, and other mineral matters, they are

[1] See Strasburger, Noll, Schenk, and Schimper's *Text-Book of Botany*, pp. 338–370, incl.; also Potter and Warming's *Systematic Botany*, p. 1, and Engler's *Syllabus der Pflanzenfamilien*, Berlin, 1903, pp. 25–50.

to be classed with animals as consumers rather than as producers, acting on the whole to diminish rather than to increase the total amount of organic material on the earth.

304. Occurrence and Mode of Life of Fungi. — Among the most important cryptogamous plants are those which, like the bacteria of consumption, of diphtheria, of typhoid fever, or of cholera, produce disease in man or in the lower animals. The subclass which includes these plants is known by the name *Bacteria*. Bacteria are now classed by some as a separate group, lower than fungi. Some of the most notable characteristics of these plants are their extreme minuteness and their extraordinary power of multiplication. Many bacteria are on the whole highly useful to man, as is the case with those which produce decay in the tissues of dead plants or animals, since these substances would, if it were not for the destructive action of the bacteria of putrefaction and fermentation, remain indefinitely after death to cumber the earth and lock up proteid and other food needed by new organisms.

The mushrooms and their allies include about one-fourth of the fungi. Some, such as the "dry-rot" fungus, mistakenly so called, cause great destruction to living and dead tree trunks and timber in economic use. The common mushroom, *Agaricus campestris*, is the most important edible species. Probably five hundred kinds can be eaten, but only a few are good food, and even these contain but little nutriment. Some species are dangerous and a few are deadly poisons. The puffballs are a small group allied to the mushrooms. Most of them are edible and of good quality.

The mildews and the "black-knot" of the plum trees are of a group which likewise includes about one-fourth

of the fungi. A considerable number are parasites, injurious to vegetation, while thousands of others grow on dead leaves, twigs, etc.

The "rust" of wheat and the "smut" of corn represent groups numbering only a few hundreds of species, which are very important because they are all parasites on living plants, many on our most important economic plants.

Fig. 160, representing another small group of destructive parasites, shows clearly how a parasitic fungus grows from a spore which has found lodgment in the tissues of a leaf and pushes out stalks through the stomata to distribute its spores.

CHAPTER XXIV

TYPES OF CRYPTOGAMS; BRYOPHYTES

305. The Group Bryophytes. — Under this head are classed the liverworts and the mosses. Both of these classes consist of plants a good deal more highly organized than the thallophytes. The most familiar liverworts and mosses are terrestrial, but some are true aquatics. Bryophytes have no true roots, but they have organs which perform the work of roots. Some of them have leaves (Fig. 167), while others have none. Fibro-vascular bundles are wanting. The physiological division of labor is carried pretty far among all the bryophytes. They have special apparatus for absorbing water and sometimes for conducting it through the stem; stomata are often present and sometimes highly developed. There are chlorophyll bodies, often arranged in cells extremely well situated for acting on the carbon dioxide gas which the plant absorbs, that is, arranged about rather large air chambers.

Reproduction is of two kinds, sexual and asexual, and the organs by which it is carried on are complicated and highly organized. An *alternation of generations* occurs, that is, the life history of any species embraces two forms: a *sexual generation*, which produces two kinds of cells that by their union give rise to a new plant; the *asexual generation*, which multiplies freely by means of special cells known as *spores*.

THE STUDY OF PIGEON-WHEAT MOSS

(*POLYTRICHUM COMMUNE*)

306. Occurrence. — This moss is widely distributed over the surface of the earth, and some of its relatives are among the best known mosses of the northern United States. Here it grows commonly in dry pastures or on hillsides, not usually in densely shaded situations.

307. Form, Size, and General Characteristics. — Study several specimens which have been pulled up with root-hairs. Note the size, general form, color, and texture of all the parts of the plants examined. Some of them probably bear *spore-capsules* or *sporophytes* like those shown in Fig. 167, while others are without them. Sketch one plant of each kind, about natural size.

What difference is noticeable between the appearance of the leaves in those plants which have spore-capsules and those which have none? Why is this?

In some specimens the stem may be found, at a height of an inch or more above the roots, to bear a conical, basket-shaped enlargement, out of the center of which a younger portion of the stem seems to proceed; and this younger portion may in turn end in a similar enlargement, from which a still younger part proceeds.

Note the difference in general appearance between the leaves of those plants which have just been removed from the moist collecting-box and those which have been lying for half an hour on the table. Study the leaves in both cases with the magnifying glass in order to find out what has happened to them. Of what use to the plant is this change? Put some of the partially dried leaves in water in a cell on a microscope slide, cover, place under the lowest power of the microscope, and examine at intervals of ten or fifteen minutes. Finally sketch a single leaf.

308. Minute Structure of the Leaf and Stem. — The cellular structure of the pigeon-wheat moss is not nearly as simple and convenient for microscopical study as is that of the smaller mosses, many of which have leaves composed, over a large part of their surfaces, of but a single layer of cells, as shown in Fig. 170. If any detailed

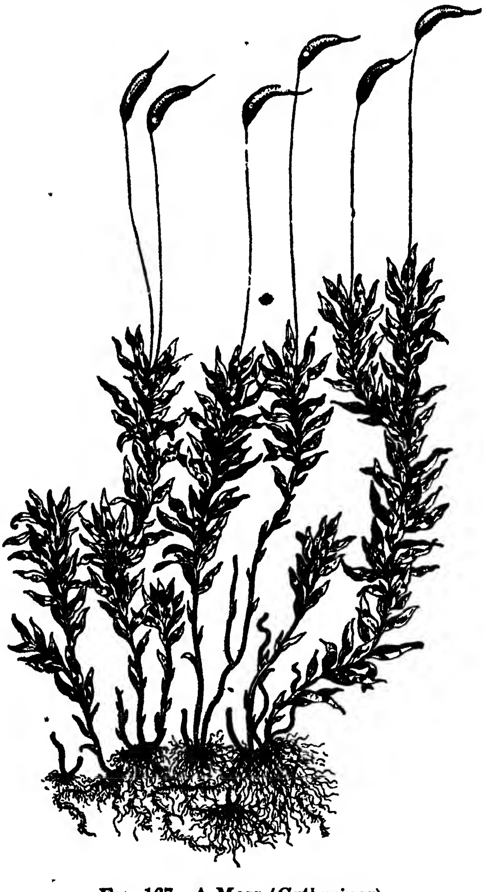


FIG. 167. A Moss (*Catharinea*).

The sporophytes of this moss are usually rather more slender than as here represented.

study of the structure of a moss is to be made, it will, therefore, be better for the student to provide himself with specimens of almost any of the smaller genera,[1] and work out what he can in regard to their minute anatomy.

309. Sporophytes. — That part of the reproductive apparatus of a common moss which is most apparent at a glance is the *sporophyte* or *spore-capsule* (Fig. 167). This is covered, until it reaches maturity, with a hood which is easily detached. Remove the hood from one

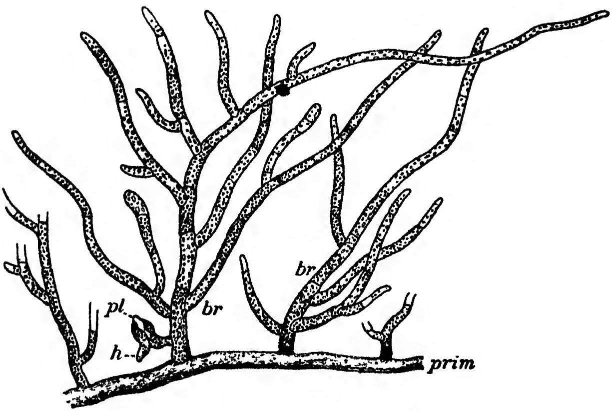


Fig. 168. Protonema of a Moss.

prim, primary shoot; *h*, a young root-hair; *pl*, young moss-plant; *br*, branches of primary shoot.

of the capsules, examine with a magnifying glass, and sketch it. Note the character of the material of which its outer layer is composed.

Sketch the uncovered capsule as seen through the magnifying glass, noting the little knob at its base and the circular lid.

Pry off this lid, remove some of the mass of spores from the interior of the capsule, observe their color as seen in bulk through the magnifying glass, then mount in water, examine with the highest obtainable power of the microscope, and sketch them. These

[1] As *Mnium* or *Bryum*.

FIG. 169.

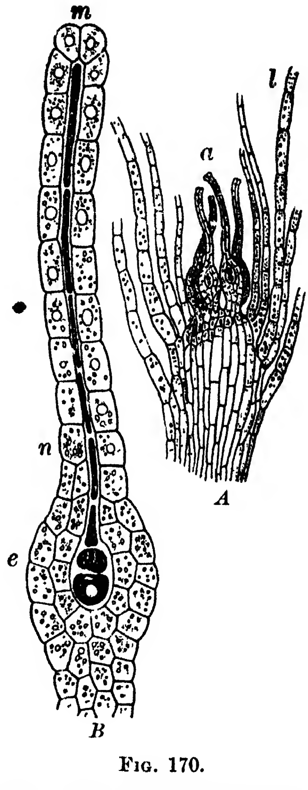


FIG. 170.

FIG. 169. The Antheridium of a Moss (*Funaria*) and its Contents.

a, antheridium; *b*, escaping antherozoids (× 350); *c*, a single antherozoid of another moss (× 800).

FIG. 170. Portions of Fertile Plant of a Moss (*Funaria*).

A, longitudinal section of summit of plant (× 100); *a*, archegonia; *l*, leaves. *B*, an archegonium (× 550); *e*, enlarged ventral portion with central cell; *n*, neck; *m*, mouth.

spores, if sown on moist earth, will each develop into a slender, branched organism, consisting, like pond-scum, of single rows of cells (Fig. 168) called the *protonema.*

310. Other Reproductive Apparatus. — The student cannot, without spending a good deal of time and making himself expert in the examination of mosses, trace out for himself the whole story of the reproduction of any moss. It is sufficient here to give an outline of the process. The protonema develops buds, one of which is shown in Fig. 168, and the bud grows into an ordinary moss-plant. This plant, in the case of the pigeon-wheat moss, bears organs of a somewhat flower-like nature, which contain either *antheridia* (Fig. 169), organs which produce fertilizing cells called *antherozoids*, or *archegonia* (Fig. 170), organs which produce egg-cells, but in this moss antheridia and archegonia are not produced in the same "moss-flower." The plants therefore correspond to diœcious ones among flowering plants.

After the fertilization of the egg-cell by the penetration of antherozoids to the bottom of the flask-shaped archegonium, the development of the egg-cell into a *sporophyte* begins; the latter rises as a slender stalk, while the upper part of the archegonium is carried with it and persists for a time as the hood or *calyptra.*

CHAPTER XXV

TYPES OF CRYPTOGAMS; PTERIDOPHYTES

311. The Group Pteridophytes. — Under this head are classed the ferns, the scouring-rushes, and the club-mosses. They are the most highly organized of cryptogams, having true roots, and often well-developed stems and leaves.

THE STUDY OF A FERN[1]

312. Conditions of Growth. — If the specimens studied were collected by the class, the collectors should report exactly in regard to the soil and exposure in which the plants were found growing. Do any ferns occur in surroundings decidedly different from these? What kind of treatment do ferns need in house culture?

313. The Underground Portion. — Dig up the entire underground portion of a plant of ladyfern. Note the color, size, shape, and appendages of the rootstock. If any are at hand which were collected in their late winter or early spring condition, examine into the way in which the leafy parts of the coming season originate from the rootstock, and note their peculiar shape (Fig. 171, *A*).

[1] The outline here given applies exactly only to *Asplenium filix-fœmina*. Any species of *Asplenium* or of *Aspidium* is just as well adapted for study. *Cystopteris* is excellent, but the indusium is hard to find. *Polypodium vulgare* is a simple and generally accessible form, but has no indusium. *Pteris aquilina* is of world-wide distribution, but differs in habit from most of our ferns. The teacher who wishes to go into detail in regard to the gross anatomy or the histology of ferns as exemplified in *Pteris* will find a careful study of it in Huxley and Martin's *Biology*, or a fully illustrated account in Sedgwick and Wilson's *Biology*.

FIG. 171. Spore-Plant of a Fern (*Aspidium filix-mas*).

A, part of rootstock and fronds (not quite one-sixth natural size); *fr*, young fronds unrolling. *B*, under side of a pinnule, showing sori, *s*. *C*, section through a sorus at right angles to surface of leaf, showing indusium, *i*, and sporangia, *s*. *D*, a sporangium discharging spores. (*B* is not far from natural size. *C* and *D* are considerably magnified.)

This kind of vernation is decidedly characteristic of ferns. Observe the number and distribution of the roots along the rootstock. Bring out all these points in a sketch.

314. The Frond. — Fern leaves are technically known as *fronds.* Observe how these arise directly from the rootstock.

Make a somewhat reduced drawing of the entire frond, which consists of a slender axis, the *rhachis,* along which are distributed many leaflets or *pinnæ,* each composed of many *pinnules.* Draw the under side of one of the pinnæ, from near the middle of the frond, enlarged to two or three times its natural size, as seen through the magnifying glass. Note just how each pinnule is attached to its secondary rhachis.

Examine the under side of one of the pinnules (viewed as an opaque object without cover-glass) with the lowest power of the microscope, and note:

(*a*) The "fruit-dots" or *sori* (Fig. 171, *B*) (already seen with the magnifying glass, but now much more clearly shown).

(*b*) The membranous covering or *indusium* of each sorus (Fig. 171, *C*). Observe how this is attached to the veins of the pinnule. In such ferns as the common brake (*Pteris*) and the maidenhair (*Adiantum*) there is no separate indusium, but the *sporangia* are covered by the incurved edges of the fronds.

(*c*) The coiled spore-cases or sporangia, lying partly covered by the indusium. How do these sporangia discharge their spores?

Make a drawing, or several drawings, to bring out all these points.

Examine some of the sporangia, dry, with a power of about 50 or 75 diameters, and sketch. Scrape off a few sporangia, thus disengaging some spores, mount the latter in water, examine with a power of about 200 diameters, and draw.

315. Life History of the Fern. — When a fern-spore is sown on damp earth it gradually develops into a minute, flattish object, called a *prothallium* (Fig. 172). It is a rather tedious process to grow prothallia from spores, and the easiest way to get them for study is to look for them on the earth or on the damp outer surface of the flower-pots in which ferns are growing in a greenhouse. All stages of germination may readily be found in such localities.

Any prothallia thus obtained for study may be freed from particles of earth by being washed, while held in very small forceps, in

a gentle stream of water from a wash-bottle. The student should then mount the prothallium, bottom up, in water in a shallow cell, cover with a large cover-glass, and examine with the lowest power of the microscope. Note:

(*a*) The abundant root-hairs springing from the lower surface of the prothallium.

(*b*) The variable thickness of the prothallium, near the edge, consisting of only one layer of cells.

(*c*) (In some mature specimens) the young fern growing from the prothallium, as shown in Fig. 172, *B*.

The student can hardly make out for himself, without much expenditure of time, the structure of the *antheridia* and the *archegonia*, by the coöperation of which fertilization takes place on much the same plan as that already described in the case of mosses. The fertilized egg-cell of the archegonium gives rise to the young fern, the *sporophyte*, which grows at first at the expense of the parent prothallium, but soon develops roots of its own and leads an independent existence.

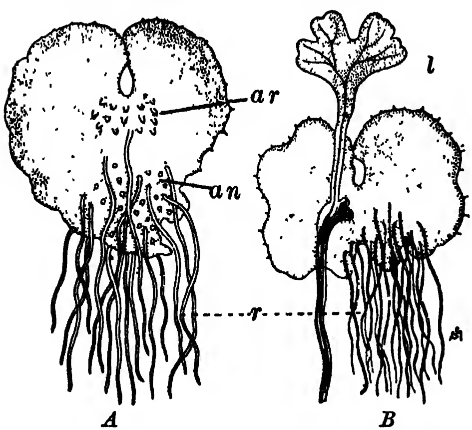


FIG. 172. Two Prothallia of a Fern (*Aspidium*).

A, under surface of a young prothallium; *ar*, archegonia; *an*, antheridia; *r*, rhizoids. *B*, an older prothallium with a young fern-plant growing from it; *l*, leaf of young fern. (Both × about 8.)

316. Nutrition. — The mature fern makes its living, as flowering plants do, by absorption of nutritive matter from the soil and from the air, and its abundant chlorophyll makes it easy for the plant to decompose the supplies of carbon dioxide which it takes in through its stomata.

FERNS

317. Structure, Form, and Habits of Ferns. — The structure of ferns is much more complex than that of any of the groups of cryptogamous plants discussed in the earlier portions of the present chapter. They are possessed of well-defined fibro-vascular bundles; they form a variety of parenchymatous cells; the leaves have a distinct epidermis and are provided with stomata.

Great differences in size, form, and habit of growth are found among the various genera of ferns. The tree ferns of South America and of many of the islands of the Pacific Ocean sometimes rise to a height of forty feet, while the most minute species of temperate and colder climates are not as large as the largest mosses. Some species climb freely, but most kinds are non-climbing plants of moderate size, with well-developed rootstocks, which are often, as in the case of the bracken-fern, or brake,[1] and in *Osmunda*, very large in proportion to the parts of the plant visible above ground.

318. Economic Value of Ferns. — Ferns of living species have little economic value, but are of great interest, even to non-botanical people, from the beauty of their foliage.

During that vast portion of early time known to geologists as the Carboniferous Age, the earth's surface in many parts must have been clothed with a growth of ferns more dense than is now found anywhere. These ferns, with other flowerless herbs and tree-like plants, produced the vegetable matter out of which all the principal coal beds of the earth have been formed.

[1] *Pteris aquilina.*

319. Reproduction in Ferns. — The reproduction of ferns is a more interesting illustration of alternation of generations than is afforded by mosses. The sexual plant, *gametophyte*, is the minute prothallium, and the non-sexual plant, *sporophyte*, which we commonly call the fern, is merely an outgrowth from the fertilized egg-cell,

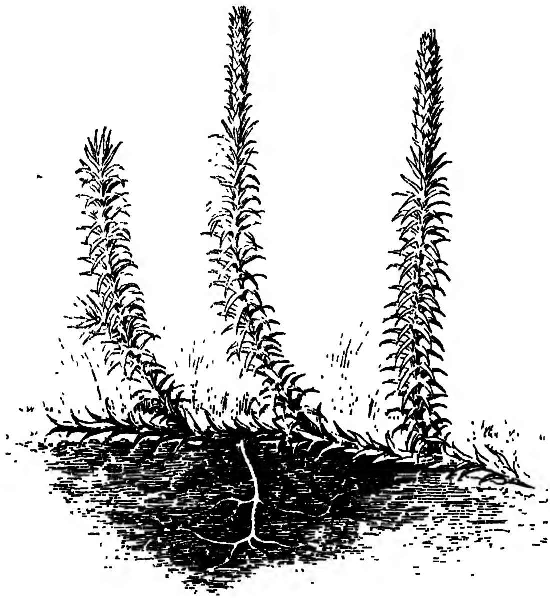


FIG. 173. Plant of Lycopodium (*L. annotinum*).

and physiologically no more important than the sporophyte of a moss, except that it supplies its own food instead of living parasitically. Like this sporophyte, the fern is an organism for the production of vegetative spores from which new plants endowed with reproductive apparatus may grow.

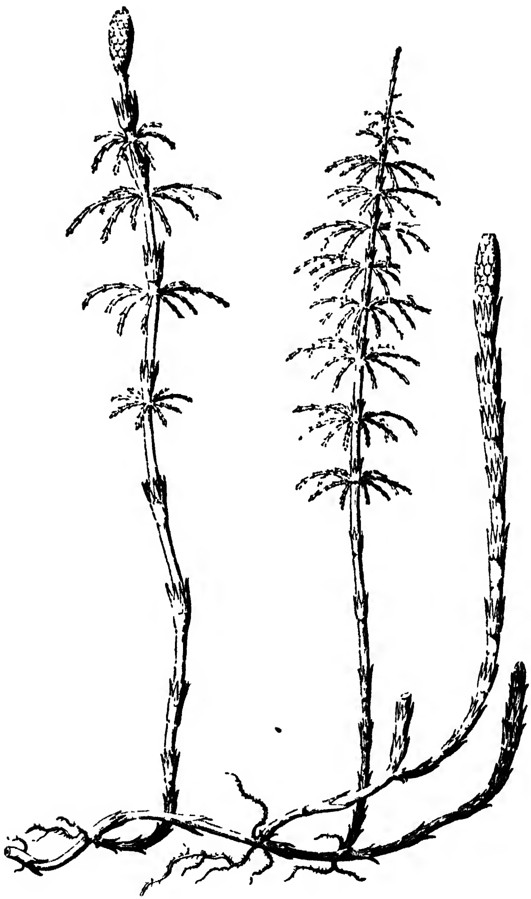


FIG. 174. A Scouring-Rush (*Equisetum sylvaticum*).

At the right is a colorless fertile stem, in the middle a green sterile one, and at the left a green fertile one.

THE STUDY OF A SCOURING-RUSH (*EQUISETUM*)

320. Occurrence. — The common horse-tail, *Equisetum arvense*, is widely distributed in the United States, east, west, north, and south. It is very often found on sand hills and along railroad embankments. The fruiting stems appear very early in the spring and are of short duration. The sterile vegetative growth follows, becoming well grown in June.

321. Examination of Rootstocks and Roots. — Examine the underground portions of the plant with reference to general size, position, color, shape, and position of notches. After studying the stems above ground insert here any evident points of comparison. Do you find any special forms of stem development suited to a special purpose? Are there any organs in the nature of leaves?

322. Sterile Stems. — Examine the stems above ground with reference to their color and mode and degree of branching. What is the character of the leaves? Do the stems in any sense serve as leaves? Observe the nodes composing the stem and note the position of the leaves on the stems. Do several appear to be placed at the same level (whorled)?

Examine with a magnifying glass the surface of the stem and note the number of ridges and grooves. Compare the number and position of the leaves with reference to these.

323. Mineral Matter in Stem. — Treat small pieces of the stem with strong nitric acid to remove all vegetable substance and note the mineral substance remaining. Treat in a similar way thin cross-sections and examine under the microscope. The substance is silica. It gives the plant its gritty feeling and its name and use as "scouring-rush." Of what use is it to the plant? Use of the same substance in outer rind of corn stem, bamboo stem, and straw of grains?

324. Microscopic Examination. — Make thin cross-sections of the stem and examine under the lowest power of the microscope. Make a diagrammatic sketch to indicate the central cavity, the number and position of the fibro-vascular bundles, the cavity or canal in each, the ring of tissue surrounding the ring of bundles, and the larger cavities or canals outside of this. Where is the chlorophyll located? Can stomata be found, and if so, what is their location and arrangement?

325. Fertile Stems. — Describe the fruiting stem with reference to general aspect, size, color, number, and length of internodes, position of spore-bearing portion, color of spores in mass. Note the shield-shaped bodies (transformed leaves or *sporophylls*) composing the cone-like "flower," and see whether any joints can be detected where they are attached. Examine the inner surface of the shields for sporangia and spores. Examine the sporangia under a low power of the microscope. Examine some spores under a higher power. Note the two bands, *elaters*, on each spore, crossing each other and attached only at the point of crossing, forming four loose appendages. Watch these while some one moistens them by gently breathing upon them as they lie uncovered on the slide under the microscope and note the effect. Also note the effect of drying. How does this affect the spores? Use of the bands?

326. Germination of Spores. — The spores germinate while fresh and form prothallia corresponding to those of ferns, but generally diœcious. The prothallium which bears the antheridia remains comparatively small, and the antheridia are somewhat sunken. The others grow much larger and branch profusely. The terminal portion becomes erect and ruffled. Near this part the archegonia are formed, quite similar to those of ferns. The embryo plant developing from the germ-cell has its first leaves in a whorl. This at length grows into a spore-plant like that shown in Fig. 174.

About twenty-five species of *Equisetum* are known. Several may be looked for in any locality and may well be compared with the one described above, in regard to form, mode of branching, and mode of fruiting.

FIG. 175. Part of a Lobe of the Mature Female Prothallium of *Equisetum*. (× about 50.)

a, mouth of a fertilized archegonium.

327. Fern-Plants (Pteridophytes). — The *Pteridophytes* (literally fern-plants) include in their general category not only ferns as commonly recognized, but several other small groups which are very interesting on account of their diversity. All cryptogams higher than mosses belong in this group. In moss-plants the individuals growing from spores and bearing antheridia and archegonia, the gametophytes, are full-grown leafy plants, and the spore-bearing plant, or sporophyte, is merely a stalk bearing a sporangium. In all the fern-plants the reverse is true. The individuals growing from spores and bearing antheridia and archegonia are of minor vegetative development (*prothallia*), while the spore-bearing plant is a leafy plant, even a tree in some ferns.

The ferns in the strictest sense have sporangia derived from the epidermis (transformed hairs), while a few plants closely resembling them in general aspect (*Botrychium*, etc.) have sporangia formed in the tissue of the leaf.

The horse-tails have only one kind of spore and are peculiar chiefly in their vegetative aspect (Fig. 174), while the spore-bearing leaves or sporophylls are arranged in the form of a cone, as already shown.

The club-mosses include some plants which, as their name implies, have a superficial resemblance to a large moss, with the addition of a club-shaped stalked fruiting spike (Fig. 173). These are the so-called "ground pines" and the running ground "evergreens" used for Christmas festoons in New England. Technically the group is distinguished by the possession of firm-walled sporangia formed singly near the bases of the leaves.

328. High Organization of Pteridophytes. — The student may have noticed that in the scouring-rush studied there

are groups of leaves greatly modified for the purpose of bearing the sporangia. These groups are more nearly equivalent to flowers than anything found in the lower spore-plants, and the fern-plants which show such structures deserve to be ranked just below seed-plants in any natural system of classification.

The variety of tissues which occur in pteridophytes is frequently nearly as great as is found in ordinary seed-plants, and the fibro-vascular system is even better developed in many ferns than in some seed-plants.

Starch-making is carried on by aid of abundant chlorophyll bodies contained in parenchyma-cells to which carbonic acid gas is admitted by stomata. In many cases large amounts of reserve food are stored in extensive root-stocks, so that the spring growth of leaves and stems is extremely rapid.

CHAPTER XXVI

GENERAL CHARACTERISTICS OF CRYPTOGAMS; EVOLUTIONARY HISTORY OF PLANTS

329. Characteristics of Cryptogams. — Something has been done in the three preceding chapters in the way of summing up facts regarding the form, structure, and mode of life of algæ, fungi, bryophytes, and pteridophytes. But before leaving altogether the subject of cryptogamous plants it is worth while very briefly to sum up a few points concerning them.

Cryptogams are often called flowerless plants, but this is a poor name for them, for the reproductive apparatus of a moss is somewhat flower-like and that of the horse-tails (*Equisetum*) is decidedly so (Sect. 328). The simplest common name for cryptogams, which is also accurate, is spore-plants. What spores are has already been stated in Sect. 265.

A very little study is enough to give some idea of what an immense variety of plant forms is comprised in the great division of the vegetable kingdom known as cryptogamous plants. This variety renders it difficult to make statements about spore-plants which will apply to all of them. Generally speaking, they are much simpler in structure than seed-plants and many are microscopic in size.

330. Importance of Cryptogams. — Because seed-plants are most of them of relatively large size and are such

familiar objects in woods, fields, and gardens, the beginner in botany is apt to feel that they are in all ways the principal plants. This is a serious mistake. In the classification of plants in Sect. 261 something of scientific accuracy has been sacrificed for the sake of simplicity. Really, according to the highest living authority on the subject, Professor Adolf Engler, seed-plants form only one out of thirteen branches of the vegetable kingdom. In their inconceivable numbers spore-plants far surpass seed-plants.

While a little scientific knowledge of plants has existed for more than two thousand years, most of our knowledge of such minute plants as bacteria dates back much less than half a century, to the time when the use of sufficiently powerful microscopes first made their study possible.

The importance of cryptogamous plants to human life and work is too great to be explained in a paragraph, a chapter, or even in a single book. From the clover field to the baker's kneading trough, from the cheese factory to the hospital for consumptives, modern life is full of practical illustrations of the bearings of cryptogamic botany on agriculture, manufactures, and medicine.

331. The Earliest Plants. — The question, What were the first forms of plant life that existed on the earth's surface? cannot be precisely answered. The earth in its solid condition probably remained for a long period as an intensely heated mass, destitute of any trace of life. Ages later, but many hundreds of centuries ago, the temperature of the globe became sufficiently lowered to admit of the existence of plant life. These earliest plants were undoubtedly of the simplest form and may very probably have been one-celled aquatic algæ. Such plants, however, would have been unlikely to leave recognizable remains

preserved in the rocks. Great numbers of fossil plants have been discovered in various parts of the world, but there is reason to suppose that all of these are comparatively late and highly developed descendants of the first plants that appeared.

332. Evidence from the Life Histories of Plants. — Every individual phanerogamic plant and every one of the higher cryptogams during its life history goes through a series of changes, — from the spore with which it begins to the most highly developed form of which that plant is capable. This gradual unfolding of organs, from a very simple spore as the starting point, means everything to the botanist. For in botany, as in zoölogy, it is a well recognized law that *the development of every individual follows in outline the course of development of its group.* During the process of hatching, while the young animal in the egg is beginning to develop into a turtle, an alligator, or a bird, the general form of the embryo is for some time much the same in all three cases. It is probable that this arises from the fact that turtles, alligators, and birds have sprung from a common ancestor, — an animal which lived in the far remote past and which united in its organization some of the characteristics of these its descendants.

Reasoning in the same way, we may feel sure from the resemblance in essentials between the prothallia of ferns and horse-tails (Figs. 172, 175) that these two kinds of plants, so different in the general form and structure of the full-grown sporophytes, have a common ancestry. This is only one rather simple instance, out of many, of likeness in the early stages in the life history of two classes of plants which are most unlike in their adult condition. By comparing in this way the successive steps in the development

of great numbers of plants of different groups, it has become possible to draw up a sort of pedigree of the plant world. This is not as yet by any means complete, but what is already known on the subject throws much light on the reasons for the existence of structures in the early part of the life histories of many plants which would otherwise seem to be wholly useless and without meaning.[1]

333. Plants form an Ascending Series. — All modern systems of classification group plants in such a way as to show a succession of steps, often irregular and broken, seldom leading straight upward, from very simple forms to highly complex ones. The humblest thallophytes are merely single cells, usually of microscopic size. Class after class shows an increase in complexity of structure and of function, until the most perfectly organized plants are met with among the dicotyledonous angiosperms. During the latter half of the present century it first became evident to botanists that among plants *deep-seated resemblances imply actual relationship, the plants which resemble each other most are most closely akin by descent, and (if it were not for the fact that countless forms of plant life have wholly disappeared) the whole vegetable kingdom might have the relationships of its members worked out by a sufficiently careful study of the life histories of individual plants and the likeness and differences of the several groups which make up the system of classification.*[2]

334. Development of the Plant from the Spore in Green Algæ and Mosses. — The course which the forms of plant

[1] See Engler's *Syllabus der Pflanzenfamilien*, Berlin, 1903, pp. vi–x.
[2] See Campbell's *Evolution of Plants* and Warming's *Systematic Botany*, Preface and throughout the work. In the little Flora of the present book, the families are arranged in the order which, according to the best recent German authorities, most nearly represents their relationships.

life have followed in their successive appearances on the earth may be traced by the application of the principle stated in Sect. 332.

Such algæ as the pond-scums produce spores which give rise directly to plants like the parent.

A moss-spore in germination produces a thread-like protonema which appears very similar to green algæ of the pond-scum sort. This at length develops into a plant with stem and leaves, — the sexual generation of the moss. The fertilized archegonium matures into a sporophyte which is the alternate, non-sexual generation. This is attached to the moss-plant or gametophyte, but is an important new organism. In the moss the sexual generation is the larger and more complex of the two, the non-sexual generation being smaller and wholly dependent for its food supply on the other generation to which it is attached.

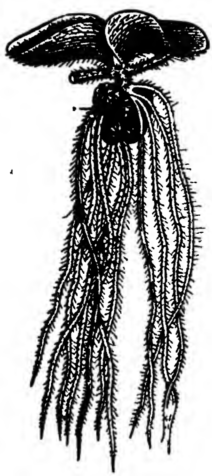


FIG. 176. A Water-Fern (*Salvinia*).

335. Development of the Plant from the Spore in Pteridophytes. — In the pteridophytes there is an alternation of generations, but here the proportions are reversed, the prothallium, or sexual generation, or gametophyte, being short-lived and small (sometimes microscopic), and the non-sexual generation, the sporophyte, often being of large size. The ferns (non-sexual generation), for instance, are perennial plants, some of them tree-like. Some pteridophytes, as the *Salvinia*, a small floating

aquatic plant sometimes known as a water-fern (Fig. 176), produce two kinds of spores, the large ones known as *macrospores*, and the small ones known as *microspores* (Fig. 177). Both kinds produce microscopic prothallia, those of the former bearing only archegonia, those of the latter only antheridia. From the prothallia of the macrospores a plant (non-sexual generation) of considerable complexity of structure is formed.

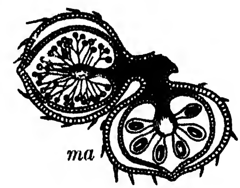


FIG. 177. Two Indusia of *Salvinia*.
mi, microspores; *ma*, macrospores.

336. Parts of the Flower which correspond to Spores.—In seed-plants the spore-formation of cryptogams is represented, though in a way not at all evident without careful explanation. The pistil is the macrospore-producing leaf or *macrosporophyll*, and the stamen is the microspore-producing leaf or *microsporophyll*. Pines and other gymnosperms produce a large cell (the embryo sac) in the ovule (Fig. 178) which corresponds to the macrospore, and a pollen grain which represents the microspore. In its development the macrospore produces an endosperm or small cellular prothallium, concealed in the ovule. The microspore contains vestiges of a minute prothallium.

In the angiosperms the macrospore and its prothallium are still less developed, and the microspore or pollen grain has lost all traces of a prothallium and is merely an antheridium which contains two generative cells.[1] These are most easily seen in the pollen grain, but sometimes they are plainly visible in the pollen tube (Fig. 123).

[1] Sometimes only one generative cell escapes from the pollen grain into the pollen tube, and there it divides into two cells.

Phanerogams are distinguished from all other plants by their power of producing seeds, or enclosed macrosporangia, with embryos.

337. The Law of Biogenesis and the Relationships of the Great Groups of Plants. — On summing up Sects. 334–336, it is evident that the sexual generation in general occupies a less and less important share in the life of the plant as one goes higher in the scale of plant life.[1] In the case of the rockweed, for instance, the sexual generation is the plant. Among mosses the sexual generation is still very prominent in the life of the plant. Ordinary ferns show us the sexual generation existing only as a tiny independent organism, living on food materials which it derives from the earth and air. In the *Salvinia* it is reduced to microscopic size and is wholly dependent on the parent plant for support. Among seed-plants the sexual generation is so short-lived, so microscopic, and so largely enclosed by the tissues of the flower that it is comparatively hard to demonstrate that it exists.

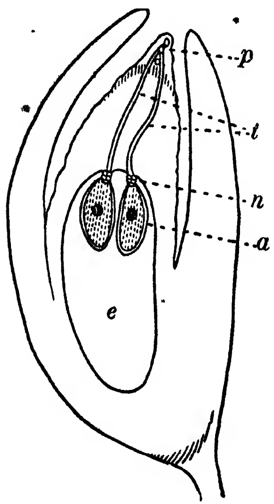


FIG. 178. Longitudinal Section through Fertilized Ovule of a Spruce.

p, pollen grains; *t*, pollen tubes; *n*, neck of the archegonium; *a*, body of archegonium with nucleus; *e*, embryo sac filled with endosperm.

[1] A good many plants of low organization, however, are not known to pass through any sexual stage.

The fact that the life history of so many of the classes of plants embraces a sexual stage, in which an egg-cell is fertilized by some sort of specialized cell produced wholly for use in fertilization, tends strongly to show the common origin of the plants of all such classes. We have reason to believe, from the evidence afforded by fossils, that plants which have only a sexual generation are among the oldest on the earth. It is therefore likely that those which spend the least portion of their entire life in the sexual condition were among the latest of plants to appear. Then, too, those which have the least developed sexual generation are among the latest of plants. Judged by these tests, the angiosperms must be the most recently developed of all plants.

If one were to attempt to arrange all the classes of existing plants in a sort of branching series to show the way in which the higher plants have actually descended from the lower ones, he would probably put some one of the green algæ at the bottom and the angiosperms at the top of the series.

338. The Oldest Angiosperms. — It is impossible to give any of the reasons for the statements of this section without making an unduly long chapter. Briefly, it may be stated that the monocotyledons are the simplest and probably the oldest angiosperms; the dicotyledons are higher in organization and came later. The descent and various relationships of the families of dicotyledons can be discovered by the study of the flower, fruit, and seed better than by the examination of the vegetative organs.

The entire pedigree of the several families cannot be represented by arranging the names of the families in a straight line. It is, however, in a general way, as indicated

by the succession of families in the Flora which accompanies this book, the Willow Family being perhaps the oldest (of the more familiar ones) and the Composite Family the youngest.

The beginner in systematic botany must guard himself from the natural tendency to feel that the simpler types of flowers, like those of the Buttercup family and the Stonecrop family, with their organs distinct and not adnate, are more perfectly organized than gamopetalous flowers. This is not the case. It is in such irregular flowers as those of Figs. 129 and 132 and in such consolidated forms as those of the yarrow, shown in Fig. 8 of the Appendix, that we are to recognize the highest types reached in floral structures.

APPENDIX

[*Additional illustrations, chiefly for use with the Flora in determination of species.*]

I. LEAF FORMS

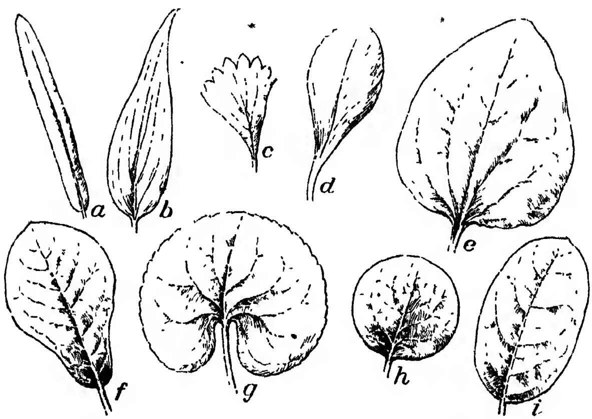


Fig. 1. General Outline of Leaves.

a, linear; *b*, lanceolate; *c*, wedge-shaped; *d*, spatulate; *e*, ovate; *f*, obovate; *g*, kidney-shaped; *h*, orbicular; *i*, elliptical.

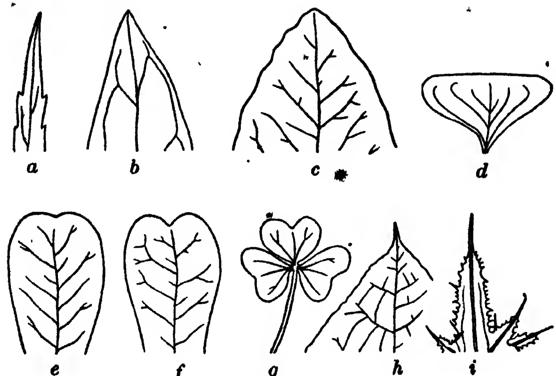


FIG. 2. Tips of Leaves.

a, acuminate or taper-pointed; *b*, acute; *c*, obtuse; *d*, truncate; *e*, retuse; *f*, emarginate or notched; *g* (end leaflet), obcordate; *h*, cuspidate, — the point sharp and rigid; *i*, mucronate, — the point merely a prolongation of the midrib.

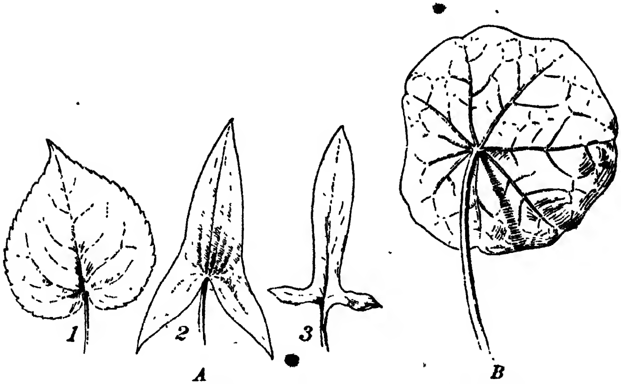


FIG. 3. *A*, Shapes of Bases of Leaves; *B*, Peltate Leaf of Tropæolum.

1, heart-shaped; 2, arrow-shaped; 3, halberd-shaped.

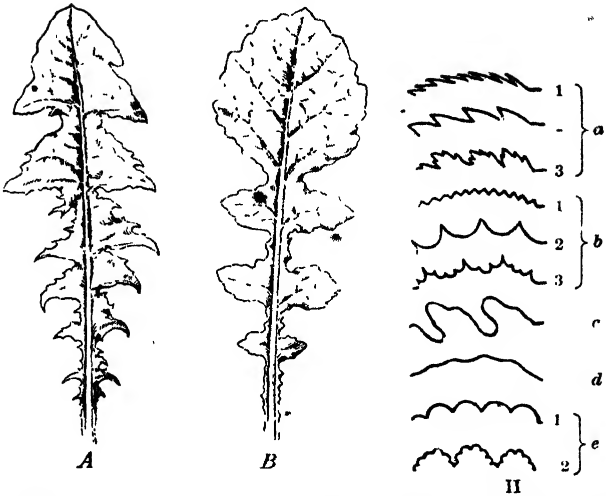


FIG. 4. I. *A*, Runcinate Leaf of Dandelion ; *B*, Lyrate Leaf.
II. Shapes of Margins of Leaves.

a (1), finely serrate ; (2), coarsely serrate ; (3), doubly serrate. *b* (1), finely dentate ; (2), sinuate dentate ; (3), doubly dentate. *c*, deeply sinuate. *d*, wavy. *e* (1), crenate or scalloped ; (2), doubly crenate.

II. FORMS OF FLOWER CLUSTERS

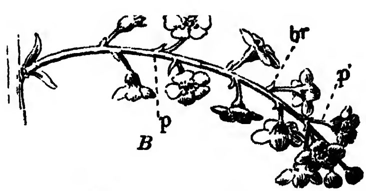


FIG. 5. *A*, Axillary and Solitary Flowers of Pimpernel ; *B*, Raceme of Common Red Currant.

p, peduncle ; *p'*, pedicel ; *br*, bract.

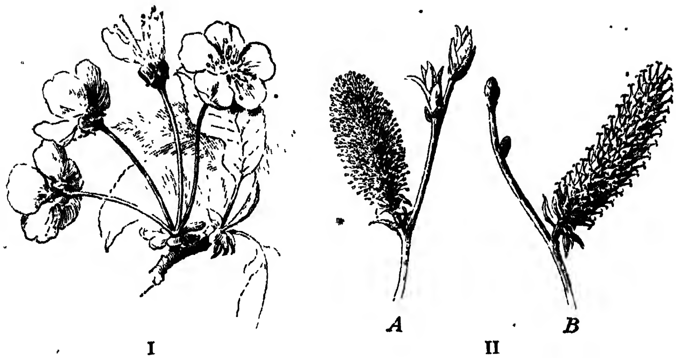


FIG. 6. I, Simple Umbel of Cherry; II, Catkins of Willow.
A, staminate flowers; *B*, pistillate flowers.

FIG. 7. *A*, Spike of Plantain; *B*, Head of Red Clover.

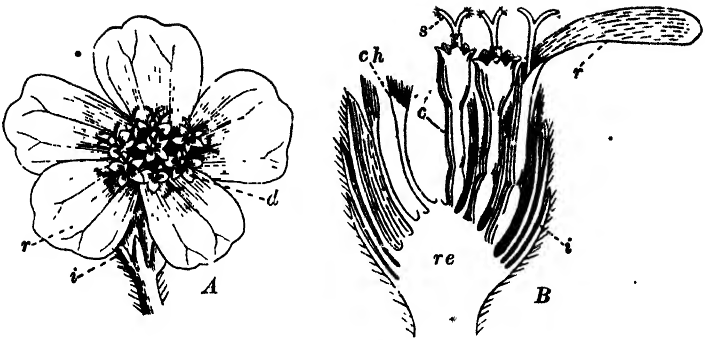


FIG. 8. Head of Yarrow.

A, top view (magnified), *B*, lengthwise section (magnified). *re*, receptacle; *i*, involucre; *r*, ray-flowers; *d*, disk-flowers, *c*, corolla; *s*, stigma; *ch*, chaff, or bracts of receptacle.

FIG. 9. *A*, Panicle of Oat; *B*, Compound Umbel of Carrot.

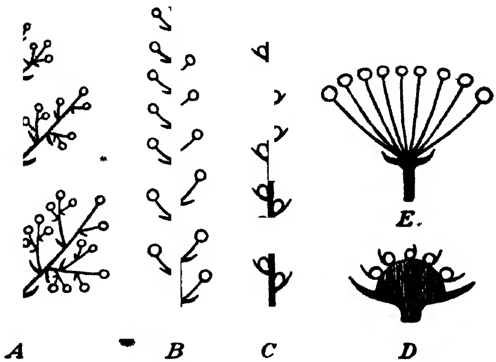


Fig. 10. Diagrams of Inflorescence.

A, panicle; *B*, raceme; *C*, spike; *D*, head; *E*, umbel.

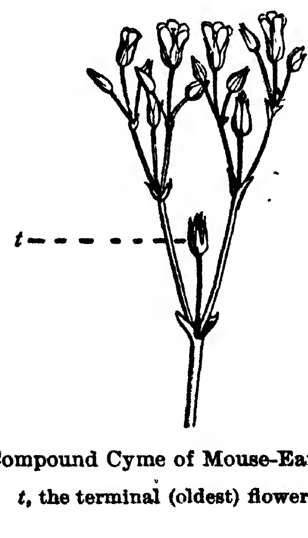


Fig. 1 . Compound Cyme of Mouse-Ear Chickweed.

t, the terminal (oldest) flower.

KINDS OF FLOWER CLUSTERS

A. **Indeterminate Inflorescence.**—Order of blossoming from below upward, or from without inward.

1. *Axillary flowers.* Flowers growing in the axils of ordinary leaves.
2. *Raceme.* Flowers with flower-stalks called *pedicels* arranged along the *peduncle* or stem in the axils of special (usually pretty small) leaves called *bracts.*
3. *Corymb.* Flowers arranged as in the raceme, but with the lower pedicels so lengthened as to make the flower cluster flat or nearly so (as in the hawthorn or the yarrow).
4. *Umbel.* Flowers with pedicels of nearly equal length, all appearing to spring from a common point, like the ribs of an umbrella. An *involucre* of bracts usually surrrounds the bases of the pedicels.
5. *Spike.* Flowers as in the raceme, but *sessile*, that is without pedicels.
6. *Head.* Flowers as in the spike, but the cluster nearly globular.
7. *Panicle.* Flowers as in the raceme, but the cluster made compound by the branching of the peduncle.

B. **Determinate Inflorescence.**—Order of blossoming from within outward.

1. *Flower terminal.* One flower borne at the summit of the stem.
2. *Cyme.* Flowers much as in the umbel, but the innermost blossoming first.

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Starred page numbers indicate where cuts occur. App. refers to the Appendix